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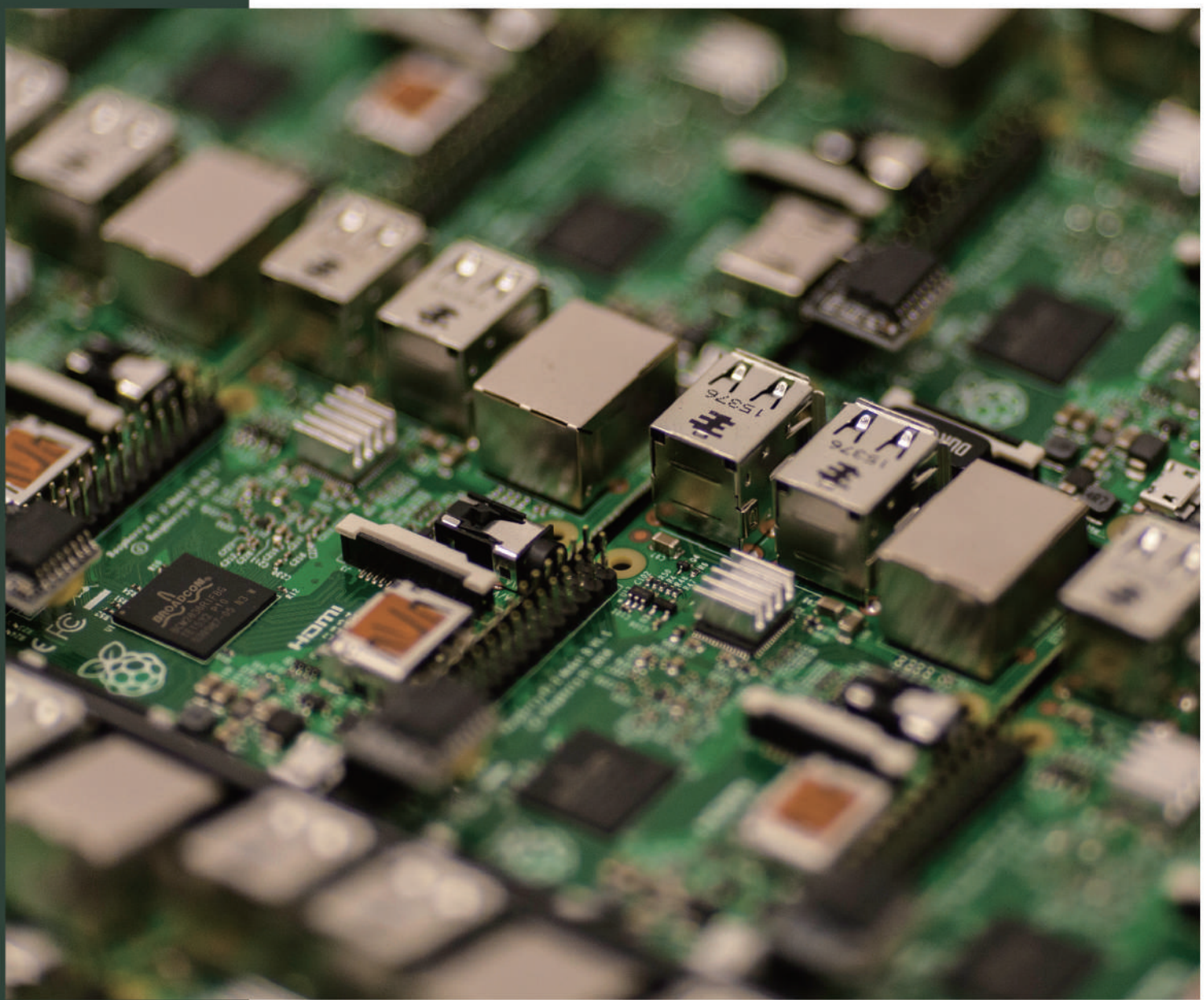

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Volume 2 | Issue 1 | April 2020 | Page 1-36
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# Contents

## Article



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ARTICLE

# On the Probability of Erasure for MIMO-OFDM

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ABSTRACT

Detecting the presence of a valid signal is an important task of a telecommunication receiver. When the receiver is unable to detect the presence of a valid signal, due to noise and fading, it is referred to as an erasure. This work deals with the probability of erasure computation for orthogonal frequency division multiplexed (OFDM) signals used by multiple input multiple output (MIMO) systems. The theoretical results are validated by computer simulations. OFDM is widely used in present day wireless communication systems due to its ability to mitigate intersymbol interference (ISI) caused by frequency selective fading channels. MIMO systems offer the advantage of spatial multiplexing, resulting in increased bit-rate, which is the main requirement of the recent wireless standards like 5G and beyond.

## 1. Introduction

As we move towards higher bit-rates and millimeter-wave frequencies, the physical layer of a telecommunication system needs to maintain reliable communication between the transmitter and receiver. This implies that:

(1) The operating average signal-to-noise ratio per bit (or $E_b/N_0$) must be as close to 0 dB as possible [1,2]. This ensures that the transmit power is kept as low as possible, which enhances the battery life of a mobile handset. It needs to be again mentioned that the operating $E_b/N_0$ of wireless telecommunication systems e.g. a mobile handset, is not specified, only the received signal strength is mentioned [3]. If $E_b/N_0$ was such an important parameter in the universities, why was it dropped by the industry?

(2) For a given $E_b/N_0$, the bit-error-rate must be minimized. In fact, it has been shown in [1] that it is possible to achieve error-free transmission as long as $E_b/N_0$ is greater than -1.6 dB even for fading channels.

(3) The transmission bandwidth should be minimized, by use of pulse shaping [4]. This allows spectrum sharing among a large number of users.

In order to achieve the aforementioned targets, the receiver must be optimally designed, incorporating the best signal processing algorithms. It is well known that the optimum receiver is a coherent receiver, that has perfect knowledge of the carrier frequency and phase, timing phase and the channel impulse response. One of the methods to obtain a near-coherent receiver is to train it with a known preamble, before the commencement of data (information) transmission. Now, the question here is: how does the receiver know that the preamble has been

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transmitted? Moreover, in the presence of noise and fading, the receiver may not be able to detect the presence of a preamble. This condition is referred to as an erasure. The subject of this work is to compute the probability of erasure for a multiple input multiple output (MIMO) orthogonal frequency multiplexed (OFDM) system, since it is expected to have applications in 5G and beyond. This work has not been done earlier.

The probability of erasure was simulated for single input single output (SISO) OFDM in [5,6]. Subsequent works on single input multiple output (SIMO) OFDM [3] and MIMO OFDM [7-10] also dealt with the probability of erasure, since the receiver was trained with a known preamble. However, the simulation results for the probability of erasure were not published.

This work is orgnized as follows. Section 2 presents the system model. The probability of erasure is derived in Section 3. Computer simulation results are given in Section 4. Conclusions and future work are mentioned in Section 5.

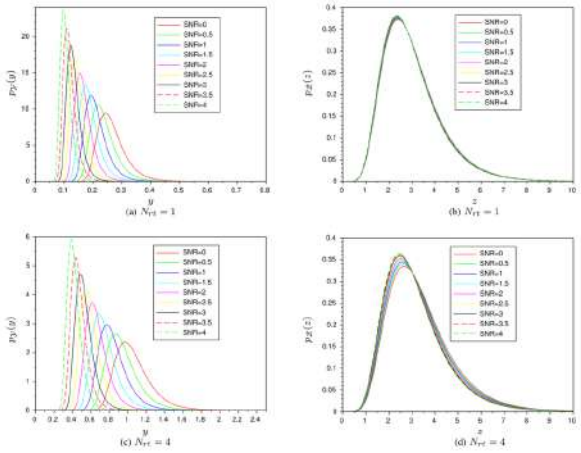

**Figure 1.** PDF of $\mathcal{Y}$ and $\mathcal{Z}$ for various SNRs, re-transmissions and $N$=4 antennas

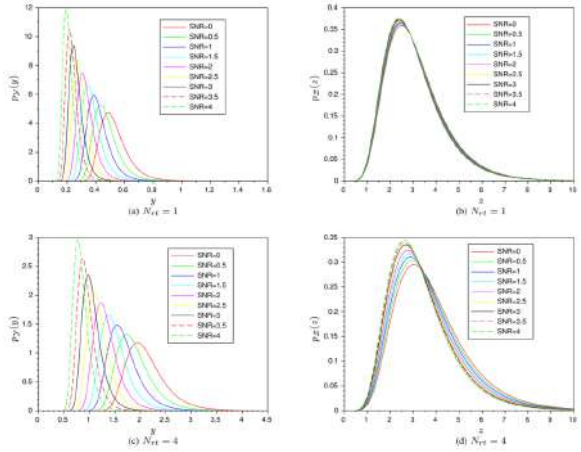

**Figure 2.** PDF of $\mathcal{Y}$ and $\mathcal{Z}$ for various SNRs, re-transmissions and $N$=8 antennas

## 2. System Model

Consider an $N \times N$ MIMO system (see Figure 1 of [9]). The channel is assumed to be quasi-static (time-invariant over one re-transmission and varies randomly over re-transmissions), frequency selective fading. The channel impulse response between transmit antenna $n_t$ and receive antenna $n_r$ for the $k^{th}$ re-transmission at time $n$ is denoted by $\tilde{h}_{k,n,n_r,n_t}$ and is characterized by (E3) in [9]. The subscripts in the channel impulse response are integers that lie in the range $1 \le k \le N_{rt}$, $0 \le n < L_h$ and $1 \le n_r, n_t \le N$. Note that the number of re-transmissions is denoted by $N_{rt}$, the length of the channel impulse response is $L_h$ and the number of antennas at the transmitter and receiver is $N$. Clearly, there are $N^2 N_{rt}$ channel impulse responses to be estimated. This is accomplished by using the frame structure given in Figure 3(a) of [9]. Recall that in the preamble phase, only one transmit antenna is active at a time, whereas in the data phase all transmit antennas are simultaneously active. The preamble symbols are drawn from a QPSK constellation and uncoded. The received signal $\tilde{r}_{k,n,n_r,n_t,p}$ during the preamble phase is given by (E8) of [9]. We assume that there is no frequency offset, that is $\omega_0 = 0$ in (E8) of [9]. The effect of non-zero frequency offset is studied in the computer simulations. At the correct timing instant (perhaps a circular shift of $\tilde{r}_{k,n,n_r,n_t,p}$ may be necessary), the $L_p$-point FFT of $\tilde{r}_{k,n,n_r,n_t,p}$ yields (E13) in [9], which is repeated here for convenience ($0 \le i < L_p$, $i$ is an integer):

$$\tilde{R}_{k,i,n_r,n_t,p} = \tilde{H}_{k,i,n_r,n_t} S_{1,i} + \tilde{W}_{k,i,n_r,n_t,p} \tag{1}$$

The subscript "$p$" in the above equation denotes the preamble phase. Now

$$\begin{aligned} \frac{\tilde{R}_{k,i,n_r,n_t,p} S^*_{1,i}}{E_s} &= \tilde{H}_{k,i,n_r,n_t} \frac{|S_{1,i}|^2}{E_s} \\ &\quad + \frac{\tilde{W}_{k,i,n_r,n_t,p} S^*_{1,i}}{E_s} \\ &= \tilde{H}_{k,i,n_r,n_t} + \frac{\tilde{W}_{k,i,n_r,n_t,p} S^*_{1,i}}{E_s} \end{aligned} \tag{2}$$

since (see (E10) of [9])

$$|S_{1,i}|^2 = E_s \tag{3}$$

denotes the energy of the preamble. The $L_p$-point inverse fast Fourier transform (IFFT) of (2) yields (for $0 \le n < L_p$, $n$ is an integer)

$$\tilde{r}_{1,k,n,n_r,n_t,p} = \tilde{h}_{k,n,n_r,n_t} + \tilde{w}_{1,k,n,n_r,n_t,p} \tag{4}$$

where the second term on the right hand side of (4) is the $L_p$-point IFFT of the second term on the right hand side of



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(2). From (4) it is clear that $0 \le n < L_h$ contains the channel coefficients plus noise, whereas $L_h \le n < L_p$ contains only noise. Typically

$$L_h \ll L_p. \tag{5}$$

Moreover

$$\frac{1}{2}E\left[\left|\widetilde{w}_{1,k,n,n_r,n_t,p}\right|^2\right] = \frac{\sigma_w^2}{E_s} \tag{6}$$

where $\sigma_w^2$ is the one-dimensional variance of $\widetilde{w}_{k,n,n_r,n_t,p}$ in (E8) of [9]. For a given $k$, $n_r$ and $n_t$ let

$$\begin{aligned} \widetilde{Z}_n &= \widetilde{h}_{k,n,n_r,n_t} + \widetilde{w}_{1,k,n,n_r,n_t,p} && \text{for } 0 \le n < L_h \\ \widetilde{Y}_n &= \widetilde{w}_{1,k,n,n_r,n_t,p} && \text{for } L_h \le n < L_p. \end{aligned} \tag{7}$$

Note that $\widetilde{Z}_n$ and $\widetilde{Y}_n$ are complex Gaussian random variables with zero-mean. Due to independence between the channel coefficients and noise

$$\begin{aligned} \frac{1}{2}E\left[\left|\widetilde{Z}_n\right|^2\right] &= \sigma_f^2 + \frac{\sigma_w^2}{E_s} \\ &= \sigma_Z^2 \\ \frac{1}{2}E\left[\left|\widetilde{Y}_n\right|^2\right] &= \frac{\sigma_w^2}{E_s} \\ &= \sigma_Y^2 \end{aligned} \tag{8}$$

where $\sigma_f^2$ is the one-dimensional variance of $\widetilde{h}_{k,n,n_r,n_t}$ (see (E3) of [9]). An erasure occurs when

$$\max_n \left|\widetilde{Z}_n\right|^2 < \max_n \left|\widetilde{Y}_n\right|^2. \tag{9}$$

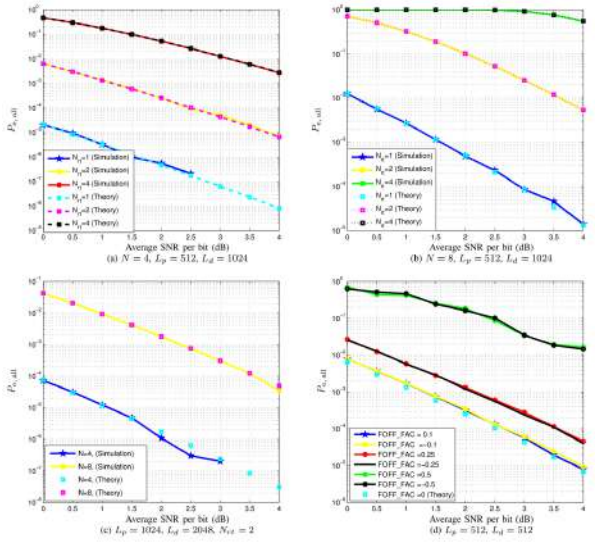

**Figure 3.** Simulation results

## 3. The Probability of Erasure

The probability density function (pdf) of $\mathcal{Z}_n = \left|\widetilde{Z}_n\right|^2$ and $\mathcal{Y}_n = \left|\widetilde{Y}_n\right|^2$ is given by (for $0 \le z, y < \infty$) [11]

$$\begin{aligned} p_{\mathcal{Z}_n}(z) &= \frac{1}{2\sigma_Z^2}\mathrm{e}^{-z/(2\sigma_Z^2)} \\ p_{\mathcal{Y}_n}(y) &= \frac{1}{2\sigma_Y^2}\mathrm{e}^{-y/(2\sigma_Y^2)} \end{aligned} \tag{10}$$

where we have assumed that $\widetilde{Z}_n$ and $\widetilde{Y}_n$ are wide sense stationary, so that their pdfs are independent of the time index $n$. Let

$$\begin{aligned} \mathcal{Z} &= \max_n \mathcal{Z}_n \\ \mathcal{Y} &= \max_n \mathcal{Y}_n. \end{aligned} \tag{11}$$

Since $\mathcal{Z}_n$ and $\mathcal{Y}_n$ are independent over $n$, the cumulative distribution function (cdf) of $\mathcal{Z}$ and $\mathcal{Y}$ is [12,13]

$$\begin{aligned} P(\mathcal{Z} \le z) &= \left(P(\mathcal{Z}_n < z)\right)^{L_h} \\ &= \left(1 - \mathrm{e}^{-z/(2\sigma_Z^2)}\right)^{L_h} \\ P(\mathcal{Y} \le y) &= \left(P(\mathcal{Y}_n < y)\right)^{L_p - L_h} \\ &= \left(1 - \mathrm{e}^{-y/(2\sigma_Y^2)}\right)^{L_p - L_h}. \end{aligned} \tag{12}$$

Therefore, the pdf of $\mathcal{Z}$ and $\mathcal{Y}$ are (for $0 \le z, y < \infty$)

$$\begin{aligned} p_{\mathcal{Z}}(z) &= \frac{d}{dz}P(\mathcal{Z} \le z) \\ &= \frac{L_h}{2\sigma_Z^2}\mathrm{e}^{-z/(2\sigma_Z^2)}\left(1 - \mathrm{e}^{-z/(2\sigma_Z^2)}\right)^{L_h - 1} \\ p_{\mathcal{Y}}(y) &= \frac{d}{dy}P(\mathcal{Y} \le y) \\ &= \frac{L_p - L_h}{2\sigma_Y^2}\mathrm{e}^{-y/(2\sigma_Y^2)}\left(1 - \mathrm{e}^{-y/(2\sigma_Y^2)}\right)^{L_p - L_h - 1}. \end{aligned} \tag{13}$$

For a given $k$, $n_r$, $n_t$, and from (9) there is no erasure when

$$\begin{aligned} P_{\mathrm{ne},1} &= \int_{z=0}^{\infty} P\left(\mathcal{Y} \le z|z\right) p_{\mathcal{Z}}(z)\, dz \\ &= \int_{z=0}^{\infty}\int_{y=0}^{z} p_{\mathcal{Y}}(y)\, dy\, p_{\mathcal{Z}}(z)\, dz \end{aligned} \tag{14}$$

where the subscript "ne" denotes "no erasure" and "1" denotes one particular value of $k$, $n_r$ and $n_t$. Now

$$\begin{aligned} I(z) &= P(\mathcal{Y} \le z|z) \\ &= \int_{y=0}^{z} p_{\mathcal{Y}}(y)\, dy \\ &= \frac{L_p - L_h}{2\sigma_Y^2}\int_{y=0}^{z}\sum_{l=0}^{L_p - L_h - 1}(-1)^l\binom{L_p - L_h - 1}{l} \\ &\quad \times \mathrm{e}^{-(l+1)y/(2\sigma_Y^2)} \\ &= \left(L_p - L_h\right)\sum_{l=0}^{L_p - L_h - 1}\frac{(-1)^l}{l+1}\binom{L_p - L_h - 1}{l} \\ &\quad \times \left(1 - \mathrm{e}^{-(l+1)z/(2\sigma_Y^2)}\right). \end{aligned} \tag{15}$$

Let

$$A_l = (-1)^l\binom{L_p - L_h - 1}{l}\frac{L_p - L_h}{l+1}. \tag{16}$$

Then


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$$I(z) = \sum_{l=0}^{L_p-L_h-1} A_l \left(1 - \mathrm{e}^{-\frac{(l+1)z}{(2\sigma_Y^2)}}\right). \tag{17}$$

Therefore

$$\begin{aligned} P_{\mathrm{ne},1} &= \int_{z=0}^{\infty} I(z) p_{\mathcal{Z}}(z)\, dz \\ &= \int_{z=0}^{\infty} \sum_{l=0}^{L_p-L_h-1} A_l \left(1 - \mathrm{e}^{-(l+1)z/(2\sigma_Y^2)}\right) p_{\mathcal{Z}}(z)\, dz \\ &= \frac{L_h}{2\sigma_Z^2} \sum_{l=0}^{L_p-L_h-1} A_l \left(1 - \int_{z=0}^{\infty} \mathrm{e}^{-(l+1)z/(2\sigma_Y^2)} \right. \\ &\quad \left. \times \sum_{a=0}^{L_h-1} (-1)^a \binom{L_h-1}{a} \mathrm{e}^{-(a+1)z/(2\sigma_Z^2)}\right) dz \\ &= \frac{L_h}{2\sigma_Z^2} \sum_{l=0}^{L_p-L_h-1} A_l \left(1 - \sum_{a=0}^{L_h-1} (-1)^a \binom{L_h-1}{a} \right. \\ &\quad \left. \times \int_{z=0}^{\infty} \mathrm{e}^{-(l+1)z/(2\sigma_Y^2)}\, \mathrm{e}^{-(a+1)z/(2\sigma_Z^2)}\right) dz \\ &= \sum_{l=0}^{L_p-L_h-1} A_l{}' \left(1 - \sum_{a=0}^{L_h-1} (-1)^a \binom{L_h-1}{a} \frac{1}{B_l + C_a}\right) \end{aligned} \tag{18}$$

where

$$\begin{aligned} A_l{}' &= \frac{L_h}{2\sigma_Z^2} A_l \\ B_l &= \frac{l+1}{2\sigma_Y^2} \\ C_a &= \frac{a+1}{2\sigma_Z^2}. \end{aligned} \tag{19}$$

Since the channel and noise are independent across $k$, $n_r$ and $n_t$ the probability of no erasure for all $k$, $n_r$ and $n_t$ is

$$P_{\mathrm{ne,all}} = \left(P_{\mathrm{ne},1}\right)^{N_{rt}N^2}. \tag{20}$$

Finally, the probability of erasure for all $k$, $n_r$ , $n_t$ is

$$P_{\mathrm{e,all}} = 1 - P_{\mathrm{ne,all}}. \tag{21}$$

While it appears that (21) is the closed form expression for the probability of erasure over all re-transmissions ($k$), receive antennas ($n_r$) and transmit antennas ($n_t$), the main problem lies in the computation of $A_l$ in (16). The reason is that $\binom{L_p-L_h-1}{l}$ takes very large values (results in overflow) for preamble length $L_p$=*512* and channel length $L_h$=*10*. In order to alleviate this problem, we need to resort to numerical integration techniques. Thus (14) is approximated by

$$P_{\mathrm{ne},1} \approx \sum_{i_0=0}^{N_{\mathcal{Z}}} \sum_{i_1=0}^{i_0\Delta z} p_{\mathcal{Y}}(i_1\Delta y)\, \Delta y\, p_{\mathcal{Z}}(i_0\Delta z)\, \Delta z \tag{22}$$

where

$$\begin{aligned} \Delta y &= \Delta z \\ &= 10^{-3} \\ N_{\mathcal{Z}} &= 10^4 \\ i_0\Delta z &= z \\ i_1\Delta y &= y. \end{aligned} \tag{23}$$

Note that

$$N_{\mathcal{Z}}\Delta z = 10. \tag{24}$$

In other words, it is sufficient to take the maximum value of $z$ in the upper limit of the integral over $z$ in (14) to be equal to 10. This is also clear from the plots of the pdf of $\mathcal{Z}$ in Figures 1 and 2 as a function of the average SNR per bit, the number of re-transmissions $N_{rt}$ and the number of antennas $N$. The average SNR per bit is defined in (E21) of [9], and is repeated here for convenience

$$\mathrm{SNR}_{\mathrm{av},b,p} = \frac{4L_h\sigma_f^2 NN_{rt}}{L_d\sigma_w^2}. \tag{25}$$

We find that in all cases, the pdf of $\mathcal{Z}$ goes to zero for $z$ >*10*, which justifies the relation in (24). It can also be seen from Figures 1 and 2 that the pdf of $\mathcal{Z}$ is relatively insensitive to variations in $N$ and $N_{rt}$ , whereas the pdf of $\mathcal{Y}$ varies widely with $N$ and $N_{rt}$.

## 4. Results

The probability of erasure results are presented in Figure 3. The results for four transmit and receive antennas ($N$=4) is shown in Figure 3(a). We see that the theoretical and simulated curves nearly coincide, which demonstrates the accuracy of our prediction. Moreover, the probability of erasure increases with increasing re-transmissions. The probability of erasure with eight transmit and receive antennas ($N$=8) is given in Figure 3(b). Clearly, the probability of erasure is three orders of magnitude higher than $N$=4, for the same number of re-transmissions $N_{rt}$. Next, in Figure 3(c), the length of the preamble and data is doubled compared to Figure 3(a) and (b), that is $L_p$=1024, $L_d$=2048 and the number of re- transmissions is fixed to $N_{rt}$=2. We see that the probability of erasure reduces by two orders of magnitude. In other words, increasing the length of the preamble ($L_p$) reduces the probability of erasure. Note that, when the preamble length is increased, the data length ($L_d$) also needs to be increased, to keep the throughput fixed (see Table 1 of [9]). Finally in Figure 3(d), we plot the probability of erasure in the presence of frequency offset ($\omega_0$). The received signal model in the presence of frequency offset is given by (E8) of [9], before the FFT operation at the receiver. We have taken



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$$\omega_0 = \text{FOFF\_FAC} \times \frac{2\pi}{L_p} \tag{26}$$

where $2\pi/L_p$ denotes the subcarrier spacing of the preamble. We see that the probability of erasure increases with increasing FOFF_FAC.

## 5. Conclusion and Future Work

In this work, we have derived the probability of erasure (defined as the probability of not detecting an OFDM frame when it is transmitted) for MIMO-OFDM systems. It is assumed that the frequency offset has been accurately estimated and cancelled. Simulation results are also presented in the presence of frequency offset, and it is seen that the probability of erasure increases with increasing frequency offset. Future work could be to derive the probability of erasure in the presence of small frequency offsets, say for FOFF_FAC<0.25. The other interesting area could be to compute $\binom{a}{b}$ for large values of $a$ and $b$.

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ARTICLE

# Information Space and Information Process: Genesis and Evolution

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ABSTRACT

In this article,the phenomenon of "information space" and its methods of study, its types, elementary structure and qualitative characteristics are discussed, the author's definition of the concept of "information" is given, the structure of the information process, and the phases, which are the basis for the evolution of the information space and the universe of human activity, are considered.

## 1. Introduction

Much has been written on the concept and phenomenon of "information space". However, most researchers have focused on its technical and technological aspects. We have chosen to examine the close relationship between information space and information processes, analyze the origin and preconditions for the development of information space, and demonstrate how the early elements of this phenomenon have defined the possibilities and conditions for its evolution.

## 2. Methods of Research

The methods of research include the following general scientific approaches: systemic approach, activity approach and process approach. Besides, we used fundamental concepts of structural levels. It was impossible to analyze such a complex phenomenon without having to recourse to philosophical categories.

## 3. Result

As a result of our study, the content and scope of the term "information space" are clarified, the structure of this phenomenon is explained, its types and characteristics are described.

## 4. Reasoning, Main Statements of Research and Evidence

### 4.1 Nature and Scope of the Concept of "Information Space"

Speaking about information and information resources, we have used the phrase "information space" more than once within which information resources exist. What is

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concealed behind the phrase "information space"? Maybe the "information space" is just a "figure of speech". Probably, these words are used as a metaphor. Or is the information space an existing phenomenon, which is the medium of information resources existence? Let us try to clarify *the content and scope of the concept of "information space"*. Let us also define the elementary and component and functional structure of this phenomenon.

We can dwell on information space only if the phenomenon of the information is clearly understood. We have made the definition of the information offered by A.V. Sokolov more exact [1]. It was caused by the necessity to indicate the reasons for the emergence of information and to show the mechanism of its emergence. Our essential definition of information is as follows: Information is a means of adapting a subject to the outside world (natural and social) through created / appropriated meanings expressed by communicative signs [2]. Many adaptation mechanisms were created, it was important for us to give a generic difference in information adaptation from other ways of adapting living organisms to their habitats. It seems that this definition solves the problem.

When the phenomenon of "information space" was only in the process of recognition, its definition appeared in the journal "University Book" in the form that was quite typical for the initial level of cognition and which characterized the scope of the concept of "information space". According to this definition, the information space included "information resources, i.e. databases and data banks, all types of archives, a system of depositories of state information resources, libraries, museums, etc.; information and telecommunication infrastructure; the mass information system; the market of information technologies, means of communication, IT development and telecommunication, information products and services; information security system; a system of interaction between the information space of Russia and the worldwide open networks; system of information legislation" [3].

As we can see, the definition is extensional, and therefore, it does not provide clarity: what the "information space" is in fact.

To investigate this phenomenon, we use the methodology of the system approach and the concept of the basic structural levels, which have again and again led us to positive results in the cognitive process. Let us briefly outline the main points that determined the course of our reasoning in the study of the information space.

Considering the information space, we denote it as a system, i.e. as a whole with integrative properties that are not attributive to its parts, it is certainly a complex system, but it is important to understand if this system is self-regulating or self-developing. The study of the information space as a system is associated with the recognition of "systematicity as an attribute property of matter" [4].

Considering information resources as part of the information space, it is important to realize the information space because according to A. V. Sokolov "the parts can be learned only based on knowledge about the whole precedes and is not determined by its parts" [5].

Like any other whole, the information space consists of elements, and only their combination (turning them into components) allows a new phenomenon to emerge. The concept of an element is something that is indivisible and identical to the *ultimate* manifestation of the whole and serves to form the remaining hierarchical levels. The element reflects such a part of the whole, which is its simplest part, quite often it is the original (generating the phenomenon) initial part. In the process of development, the original structure of the whole can be enriched by the appearance of new elements having their designation and their functions. The term "component" is also called the part of the whole, but the component can have a complex structure, and this term denotes "the facilitating force, the partial cause that influences the result" [6].

Elements of any phenomenon can act as components if it is described precisely through a combination of individual elements. A set of components determines the state of any phenomenon at different stages of its ontogeny. Proceeding from such an understanding of the whole, investigating the phenomenon of "information space," we will find out the intentional characteristics (content) of this concept and offer its essential definition, defining those elements / components that provided the original state of the information space and which *were not lost* in its evolution.

The term "information space" has emerged relatively recently. In Russia, it was actively used concerning the discussion of the issues of state information policy and the adoption and implementation of the concept of the information society. For example, in the "Concept of the Information Society Formation in Russia" adopted in 1995[7], it was noted that "the formation of an information society" .

## 4.2 Genesis and Evolution of Information Space

We start describing the genes is an devolution of information space from restoring the moment of its genesis and considering the process of its development.It is known that for the scientific reproduction of any object under study, it is effective to restore the sequence of appearance of each of its elements. As O. P. Korshunov notes, it is necessary to start from the initial point of origin, "from the simplest cell, considering the object under study in the

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dialectical unity of its reality and development" [8]; "It is possible to correctly understand the current state (structure of functioning) of an object only based on its genesis. At the same time, it is impossible to identify a genetically initial point without analyzing the modern, most developed object" [8].

Today, most people associate the information space with new information technologies, with the processes of their creation and implementation. Does it mean that the information space didn't exist before the advent of computer technology? One of the authoritative Russian specialists in the sphere of information, O. V. Kedrovsky believes that the information space "exists (regardless of concepts and programs) as one of the main conditions of our life" [9]. No doubt, this statement is true. The system phenomenon of "information space" can reveal deep roots. It is an attribute of the information process as such.

We borrowed the description of Information Process from V. Z. Kogan [10] but some additions and refinements were made to his scheme. The Information Process begins with the collision of the individual with reality, it is a Pre-Phase of the process, it includes contemplation and perception, through which the reflection of fragments of reality (facts of existence) takes place in the consciousness and as a result, sensory images are formed. The image creation opens the phase of information production, it allocates the following semantic procedures: representation, image creation and the introduction of meaning in it, as well as the establishment of a relationship between meanings. But, the sensory image is difficult to keep in memory, it may disappear after a while. The short life of image, preservation results in the necessity of its designation coding through the code, symbol, i.e. through the sign. The designation through the sign provides the materialization of meaning, the creation / use of the sign is the most important element of the process of emergence / origin of the information. Signs arise as a particular agreement between individuals and ultimately form a language. The information production phase ends with the establishment of an information product. The created information is stored in memory or remained recorded on some media- this is the phase of storing information. The stored information can be transferred to another individual who will accept signs, decode them, and extract a meaning - these processes are called the information transfer phase. The information transfer is the beginning of communication activities. The phase of information transfer includes time and spatial characteristics, i.e. communication can be characterized by the time necessary for the information transfer and the possible distance (available for communication) between the communication participants. The phase of transfer is followed by the phase of information consumption, it includes the sign perception and the process of its recognition, decoding i.e. the transfer of the sign into the meaning. Then there's the inclusion of meanings in the consciousness of the individual who has received the information, so the establishment of relationships takes place between meanings and signs denoting them, all these procedures can be considered semantic phenomena. The post phase of the information process is the use of information; the last phase is the beginning of other, non - information activities. In the post phase, there is a metamorphosis: the information product turns into an information resource, which together with raw materials and the tool is used by a person in all kinds of activities. Such processes are present in many spheres of activity, for example, flour is the product of milling and the raw material resource for bread-baking, there are many examples of the use of flour. As for information resources, we would like to add: today, it is generally recognized that they are necessary and an obligatory component in the production of material and spiritual wealth, the description and mathematical calculations of the information resources transformation into tangible goods or services are found, for example, in B. E. Odintsov and A. N. Romanov [11]. The information resource creation is the result and achieved the goal of the information process. Moreover, the achievement of the goal is a criterion that allows us to recognize the process as successful. Besides, the information created in each process has a clear applied purpose: either it is a resource for production / education / leisure or it can be a resource for the continuation of scientific knowledge.

For us, the constituent elements of the information process are "abstractions of the first kind, they form the primary, so-called source and empirical material of cognition" [8] of the phenomenon of information space that emerges as a result of the development of the information process. Proving this statement, we use the words of O. P. Korshunov. The concepts of "process" and "system" are inextricably connected. One of the postulates of the systemic approach is as follows: there can not be systems about which one could say that they exist without a process [12].

### 4.3 Evolution of Information Space and Information Barriers as Objective Factors of its Development

In the process of evolution, the information space becomes an extremely complex system phenomenon. Its current level is characterized by an extremely diverse set of its components. Each phase of the information process



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generates "new" kinds of material and spiritual activity and some interrelated and interdependent social and systemic phenomena. Thus, the information production phase gave rise to science and artistic creativity. Under the influence of a temporary factor, the information production phase has isolated the information storage phase in the information process structure, the severe need for communication for the survival of the society has formed the information transfer phase, and various types of information, including documentary activity, were formed on these two phases of the information process. The consumption phase has formed an information component in all types of material and spiritual production. In post-phase, when information is used in a particular activity, the goal of the information process is achieved and information is included as an adaptive tool component of spiritual and material transforming activity.

Revealing the evolutionary transformation of the information space and the information resources that exist in it, we will not be able to avoid the description of information barriers because they create the problem that mankind overcomes moving along the road of civilization, including technological progress. On the way of information advancement, some barriers appear, these are physical obstacles related to time, distance, and terrain features.People began to overcome the physical space barrier, which was originally generated by the limitations of sensory perception, by amplifying sound and light signals. Over time, technical capabilities have increased, and today, mankind has very successfully overcome these information barriers via printed and electronic communications, it contributes to the achievement of high-quality information space in terms of length, volume and density. Now, the issue of overcoming territorially remote objects is being solved both olfactory, tactile and tasty means. The efficiency of overcoming territorial barriers increases by many times due to the use of technical progress capabilities, in particular, information and communication technologies. However, the progressive development of the information space generates other information barriers of a different nature, and *the need to adapt* a person to the information space through overcoming various information barriers largely explains the appearance of the species diversity of information resources.

Physical (territorial, temporal, etc.) information barriers that restrict access to information are genetical first. To overcome these barriers, a person records information, creates a document, and then collects and stores documents, so there is a social documentary institution that has communicative, cumulative and memorial functions. Largely, the functions of the information institution are set by the documents that this institution stores and transmits during the implementation of different stages of the information process. Implementation of these functions generates technologies for collection, storage, and also "memorization" of documents through the creation of bibliographic information. All these technologies are aimed at primary and secondary documents and become the basis for the provision of corresponding services. The creation of bibliographic information and the subsequent emergence of other information retrieval languages allows an individual (often with the help of an information institution) to overcome navigational and search (spatial) barriers. These barriers are overcome during the implementation of the navigation function of the information institution through the provision of identification and search for documents. To overcome navigational and search barriers, an individual must have a certain level of information culture. Another group of information barriers, which we called de-unifying, is related to the fact that publishers and other subjects of the information space don't comply with standards for the creation of documents and their description with the help of bibliographic, secondary semantic and other models, which prevents from ordering information processes and jeopardizes the integrity of the information space. From content, purpose, language, material construction, sign and others, the multiplicity and variety of documents gives rise to assorted information barriers that are overcome through the implementation of the selective function of the information institution, through the creation of technology for selecting documents for storage and technologies for their provision in compliance with the requirements and social characteristics of information consumers. Due to the selection of documents, a quantitative information barrier is also overcome. It reflects the inability of the consumer to master all the documents suitable for him in terms of temporal and physiological characteristics. The selective function and corresponding technologies can be aimed not only at overcoming information barriers but also at creating ideological, educational, information barriers that are set by the founder of the information structure, as well as by the moral, ethnical and legal norms of the society. As we see, the adaptation of a person to the information space generates not only a specific variety of information resources but also a variety of information technologies. Today, some of them are now called archaic, part of them are referred to as new information (communicative) ones.

### 4.4 Concept of "Information Space"

It is important to find out what is hidden behind the concept of "space"because it is known that the most essential

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properties of the original phenomenon are inherited by all of its later forms.

In mathematics, the opposite of space is the point. One of the prominent contemporary philosophers, A.V. Nesterov in the article "Philosophy of Information" defines a point as a collection of elements consisting of one element, and contrasts it with a space consisting of a set of points [13]. Nicholas of Cusa found the connection between the point and space even in the 15th century [14]. Due to the contribution of Nicholas of Cusa, it became possible to define *space through the unity of discontinuity and continuity*.

In philosophy, the category "space" is one of the most developed. Space and time are forms of being of matter. Species concepts are formed from the generic concept of "*space*," and the category "space" has the greatest level of abstraction. From this point of view, the definition of space given by the Polish philosopher Ellen Metzger is rather revealing. "In addition to the ability to be *filled*, space has no other property; if we abstract from *setting a separate place and its filling*, there is nothing empty and dead" [6] (italicized by me - T. B.). Contemporary philosophers distinguish real space, it is the object of study in Science disciplines, and thanks to its study, conceptual space emerges,"i.e. some scientific idea about real space and perceptual space, i.e. apparent space." [15].

Perceptual space is a space perceived by a person. The development of perceptual space is connected with the individual's activity, individual structures of the society or the society as a whole. When studying the information space, the methodology of the spatial approach is the most effective one. That approach was developed by us. The essence of the spatial approach and its *basic procedures* used in this cognitive tool are described in the article "Methodology of spatial approach in library science: the prevalence and specificity of the application" [16]. Procedures aimed at studying the information space include determining the purpose of the emergence and development of space; identifying parts and elements of the hierarchical structure of space; identifying and typifying subjects of space; the study of integrative processes occurring between subjects of space; identifying subject (individual or organization) performing the functions of the chief designer of the space under study; harmonizing general and specific criteria for assessing the functioning of space; defining conditions for preserving the integrity of space and the mechanisms for achieving its unity.

The space filled with information is created by the person and, hence, it can be considered from the activity approach. According to the activity approach, all components of activity can be united only with the help of the goal. The goal is always set outside of an individual system by a system of higher rank. No doubt, the goal of creating an information space is the formation of a comfortable human environment, filled with information that is available to a person in the course of his activity and used for it.

In philosophy, "space is characterized by the extent, structure, co-existence and interaction of elements in all material systems" [17]. These generic characteristics of the concept of "space" are used to denote extended, structured and, crucially, coexisting and interacting objects associated with a particular place. The place of filling information can be an extremely small territory (regarding a document, it is limited by the text, file, page) and the territory of the region, country, and the world (globe).

The parameters and characteristics of the information space are determined by the properties of information, which became the basis for its creation and generated information communication. After all, the information mobility has become a factor in the information space, i.e. property of expansion in space. Information communication is a prerequisite for the emergence of an information space. Nevertheless, the emergence of information is the first stage of human adaptation to the environment and (or) the prerequisite for further transformation of the environment through activity. Thus, for the sake of adaptation to the environment, due to the communication of information, the information space emerges and expands, and it has the property and functions of instrumentality, supportiveness, it is an infrastructural part of the society. The growth of information in time and the diversity of its types caused the increasing complexity of the information space, and, at the same time, it became a factor contributing to the emergence of new qualities (external manifestations) that the information and space did not have.

To consider the information space, we will have to turn to the notion of "relations". The concept of "space" was born in mathematics, where it is defined as the set of objects between which *certain relations* are established. The philosophical definition of space emphasizes that its very essence is the coexistence of interacting objects. Moreover, interacting objects are those objects that enter into some *relations*. According to the Brief Philosophical Encyclopedia, the theory of relations studies "the moment of the interconnection of many kinds of things that have a subjective or objective, abstract or concrete form" [6]. The decisive difference between the term "relation" and other concepts is in their relative generalization. "Relations is part of a hierarchy based on the degree of specificity or limitation" [6].

Without referring to the term "relations," it is not only



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impossible to describe the information space and to form the corresponding concept, but it is also impossible to clarify its boundaries and its specificity. After all, the definition of the information space shall reveal the logical relations *(connections)* existing between its essential, primarily, *functional and structural elements*.

### 4.5 Types of Space and Its Structuring

Information space can be structured by the characteristics of information resources, which are determined by their intended use for a particular area of activity. In this case, we can talk about the information space - scientific, recreational, production - created following the objectives of the activity. The use / consideration of information properties allows to optimize the information process and to create an information space (as a model of the real world) with minimal means. Thus, for example, the characteristics of the purpose of the information resource are used in the formation of the industry-specific and / or departmental information space; in turn, the features of the functioning of an information space act as a factor in the successful activity of the individual or certain social groups. Each subject, each of the spheres and industry activities forms its own information space, the specifics of which is largely determined by certain types of information resources. Thus, such property as information structuring sets different types of relations between objects of the information space in the framework of both individual information phenomena and the information space as a whole.

However, while reproducing the information space in the process of thinking activity, the cognizer must always remember that all spheres of information communications have the status of server, or tool concerning the basic, served sectors. At the initial stage of the society development, the information space served as a more successful adaptation of people to the natural environment of their habitat, it was a tool of object-transforming activity aimed at satisfying the human physiological needs and was filled with appropriate types of information resources. Subsequently, when other activities emerged, the information space began to serve these types of activities and the goals of the entire universe of human actions, and it consequently got filled with the most diverse types and forms of information resources that the person created. It can be explained by the fact that the objectivity of the emergence of different types of information space is associated with the mandatory information component of any activity. After all, "any activity is procedural regarding its aims, it is proportionate to the acting person by results" [18]. and proportionality is very often associated with the possibilities of awareness (understanding) and assimilation of meanings contained in the information resource.

The phenomenon of information resource is integrated with the purpose of the activity. To achieve the goal of the activity, i.e., various processes are directed at receiving its result: motor, technological, and mental ones. The latter usually precedes any other and have an informational nature. Information manifests its generic properties in information phenomena, naturally becoming an objective factor of their diversity. Hence, the more complicated the universe of human activity is, the more complex and diverse the relations between information phenomena (objects) become, i.e. the information space becomes more complicated. Yu. S. Zubov and N. A. Slyadneva say that "space is primarily estimated through its development, the saturation with traces of human impact, its signification (toponymy) is manifested through informativeness,"noosphere" [19].

This is how "synergetic spatiality is manifested as a human-like, body-mastered environment" [20], and increasingly this environment becomes an artificial nature where a person exists.We do not live and act in the primordial world of nature, but in the "technosphere," man is a kind of hybrid of the organism and the technical device [21].

The level of saturation of the personal information space with specific or abstract concepts determines the differences between the individuals' information thesauri. As it is typical in computer science, the term "thesaurus" is used here to mean "a systematized set of data about a sphere,thesaurus allows to model the world economically" [22]. Formation of the thesaurus, its enrichment with new meanings is the main content of the information activity of the individual.*The information thesaurus is a system of semantic images*, which are a synthesis of visual, auditory, olfactory, taste, tactile images, i.e. images formed through all five senses given to a person by nature. It is also a system of concepts formed by semantic images. Our understanding of the individual information thesaurus is closest to the definition of the "subjective thesaurus" given by B.M. Velichkovsky. He considers this concept as "organized knowledge, belonging to the subject, about words and other verbal symbols, about their meanings, about the relations between them, and about the rules, formulas and algorithms used to manipulate these symbols, concepts and relationships" [22].

This approach reveals the dialectical relationship between knowledge and language and allows us to talk about the information thesaurus as an ideal structure. To render our views on the essence of the information space of the society, it will be quite enough to operate with the notion of an "individual information thesaurus" in the above-mentioned meaning without further delving into its

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structure and mechanism of emergence.

Thus, information activity, like any other, is proportionate to the acting person. The individual's informational thesaurus is something that a person can embrace with his consciousness, first, at the level of contemplation, and then at the level of abstractions, and after that systematize the received abstractions. In other words, the individual interacts with the habitat with the help of his thesaurus and adapts to it. Material and spiritual objects serve as a medium. Thus, the functioning of an individual thesaurus becomes the basis for the emergence of *an individual / personal information space*.

N.B. Zinoviev introduces three types of individual personal space: object, interpersonal, and cognitive [23]. Let's see how these types of space are related to each other, as they are "absorbed" by the information space of the individual, and then by the information space of the society, during the development of the information process. The *object* space is stable enough regarding the time factor (long-lasting), but its duration limit is determined by the ability to perceive / reflect objects through the senses (through seeing, hearing, etc.). However, when objects are reflected in the human mind when they are named (creating / using nomens), they (objects) indirectly begin to be present in the mind of the individual in the form of images and lexical (linguistic) units, and in this form "reflected and named objects" become elements of the *cognitive* space. The limits of the cognitive space are related to the human intellect and qualitative characteristics of his / her memory. So, the individual cognitive information space is formed due to the interaction of the individual with other objects of space, to which his thought is directed. In this case, information is *consumed*, and enrichment and / or clarification of the semantic images of the information thesaurus often occurs. In the emerging human consciousness, in the ontogenesis of the individual, fragments of the reflected world are combined into a single picture of the world, which is sometimes distorted, sometimes more or less true, but originally imaginative, then verbal and figurative, and finally conceptual. In the individual's mind, the product of the reflection of the objective world as a whole or its units and structures turns into knowledge. The cognitive space is based on the lexical *units of the language*, when they are transmitted to another individual, *interpersonal* space emerges with the help of speech, thus the interaction of the information creator and information consumer takes place.

Information communication is possible only in material form, therefore *oral speech*, together with an informational thesaurus created with the help of natural languages, are obligatory *components* (i.e., elements acting in combination and unity) of the initial pre-verbal and / or verbal (word) forms of the information space. The information space of the society developed simultaneously with the word (oral communication). It was necessary as one of the conditions for the success of the joint subject-transforming activity of individuals that formed the society.

The *subject* creating, cumulating or transmitting (disseminating, transmitting) information is *the center of the information space*. The subject is created by a system of a higher level. Regarding the information space, it is society. Interpersonal space is limited by the number of subjects of communication. If the number of subjects of communication increases, it becomes necessary to coordinate their actions, i.e. information transfer *management* is required, so communication process management emerges, and the information space is ordered. New functions are assigned to one of the subjects of communication, it regulates the sequence of the exchange of information messages. For example, in a family, as in a minimal cell of the society, the head of it is usually responsible for managing interpersonal communication, the elder or leader is responsible for it at a tribe meeting; in contemporary situations, the chairman of the meeting is the responsible one. With interpersonal information communication, new information is entered into the general information flow of the information space, and each of the subjects accumulates from this general information space into their individual space something that corresponds to their intellectual level, needs and interests. However, because of functioning as a manager, the subject that manages the communication process organically tries to cumulate the transmitted information in full. As a result, their information space is more saturated with meanings than others' spaces. Thus, even in the structure of interpersonal oral verbal space, with an increase in subjects of communication, an element that provides *a common information space* objectively arises - it is the manager of the communication process.Based on interpersonal space, the social information space is formed, and the *managerial element* in it becomes an objective (necessary) and organic *component*.

Therefore, the most common form of the information process in the form of verbal (oral) communication is the initial form in which it is possible to single out the original elements: the information creator, the information consumer, the word / speech. Information creator and consumer have a resource function - they assign meanings and render them via communicative signs, i.e. via speech, the latter is the rendered information, and therefore it has a communicative function. When the information process changes from the interpersonal to the social one, the manager appears with an organizational (organizational and



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managerial) function.

Nevertheless, such an obligatory characteristic of space as *the place of filling* (see the definition of space given by Metzger and cited above) makes us recognize *the territorial sign that came from the physical spacethe initial basis* for structuring the information space of the society and pay attention to its study.

The common territory and joint activities led to joining individuals within the framework of the first societies. The first form of society was the clan. Then comes the tribe. The tribe is a society that precedes the formation of states. In the early stages of development, the information space meaningfully consisted of informational thesauri belonging to members of very limited human communities - clans, tribes, which shared family ties, common language and a common place of residence (a territorial sign of the society). The primitive information space was not rigid, it was neither hierarchical nor centered, or rather, it was hierarchical and centered to the extent there was hierarchy and centralization in the organization of the community. With the increase in hierarchy and centralization in the organization of the society in the form of tribes, the level of hierarchical organization and information space increased. The decisive factor in the development of human society was its unification in the form of the state. The state becomes the main subject managing the creation of a *territorial* information space.

At the early stage of the development of the information space, its main objects were individual information thesauri of members of the society, in this form, there were information resources that served as the initial basic element of the information space of the first societies. The specificity of the information space of the ancient people was determined not only by the ways (mechanisms) of managing communication processes (i.e., the functioning of the managerial component) but also by the features of their cognition, the level of the language development. Primitive people had a figurative and verbal reflection of the world.

Consequently, their information space was filled with images. The pre-conceptual level of cognition led to the fact that the group consciousness of the ancient people created an information space based on very specific concepts. Gradually, people who mastered abstract-conceptual thinking appeared in the bosom of this human community, and the results of their information and thought activity were added to the information thesaurus of each of them and entered the information space of the society. The further development of the society led to an increase in the number of people with abstract thinking that contributed to the language development, and further to the development of science and knowledge-based practice and, in turn, it enriched the individual thesauri of members of the society.

Contemporary society is highly differentiated in terms of the level of its members' consciousness development. There are people with thesauruses, which include scientific knowledge; there are carriers of mass conceptual consciousness arising from the obligatory education and mass communication media functioning; as well as individuals whose consciousness remains primarily pre-conceptual, including only separate elements of conceptual thinking. Therefore, the peculiarities of individuals affect the quality of their information space, which is developed and constructed by them in the process of their ontogenesis, and indirectly affects the quality of the information space of the society.

Hence, the quality of the information thesaurus is determined by the subjective abilities of a person to fully and multifacetely reflect and realize the reality, to see the interconnection of its objects, to operate with meanings to a certain degree. V.Z. Kogan asserts that "the picture of the observed and reflected world can be adequate or distorted depending on the thesauruses of different modalities. In the end, nature and society don't speak to people by themselves, but in the form in which they are revealed through our way of posing questions, and there is the thesaurus at the bottom of the latter" [10]. The individual's information thesaurus is subjective and changeable. It is impossible to completely remove the information subjectivity, but for the sake of concerted action, it is necessary to reduce it as much as possible, to unify it. According to the definition given by Yu. N. Stolyarov, "knowledge is always objectified" [24]. The structuring of information, its integration into the information thesaurus of an individual or society, i.e. the transfer of information to knowledge [25], and the objectification of information. The truth and consistency of knowledge are tested by practice (experience), i.e. objectification is carried out in the phase of information use.

The information space of the individual is constantly replenished because of the appropriation of information that has been already created by someone else and due to the continuous process of reflecting the physical (material) and spiritual objects of the human environment, by transferring physical objects to the ideal (mastered by consciousness) via the creation and / or assimilation of words that are selected / created for their designation. The functioning of the information thesaurus, which can exist only through a word (language), is *a sufficient condition* for the emergence of the information space of the individual. The individual's information thesaurus is *the ultimate whole phenomenon in the information space of the soci-*

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*ety*, its division into components upgrades the analysis to the level of semantic or other units within the information thesaurus. An example of such a subdivision of the information space was given when the framework of the concept of "individual thesaurus" was discussed and when the individual objective, cognitive and interpersonal space was reproduced.

*The individual's information thesaurus* created and functioning via the language and transmitted via speech, is *an individual information space* and at the same time, *it is an element of the information space of the society*, its original, initial part. The information space of the society is always external concerning the individual's information thesaurus. Due to their subsequent deployment (and transmission), information thesauri of individuals form the information space of the society. First, the information space of the society is a chaos of sensory images, created meanings, individual signs and words, then it is ordered by the formation of a language system and after that, the informational space of the society appears as an organic whole at any stage of development. It is known that an organic whole is a self-developing system. "Integrity is a fundamental characteristic of a complicated system, and at the same time, it serves as a criterion for its development, while the phenomenon serves as internally contradictory, where its various components are in a state of competition and mutual enrichment" [26]. The basic sign of an organic whole is its dialectical dismemberment [8]. The information space of the society and individuals' information thesauri constitute the whole and represent the unity of opposites in their development. The information space of the society is enriched due to individual thesauri of the members of the community and nourishes them because the part and the whole are united, and therefore, from this or that perspective, they convert into one another without difficulty [8]. By its quantitative and qualitative characteristics, the information space of the society exceeds the simple sum of individual information thesauri, as a systemic phenomenon, it has much greater potential for successful functioning.

### 4.6. Qualitative Characteristics of Information Space

It is difficult to form the social information space and it is explained by the discreteness of messages (rendered fragments of information thesauri) and the subjects who create and receive them. Discreteness of information messages is obvious, but both information creators and consumers are also discrete. Individuals have temporary limitations related to a person's life expectancy. So in the development of the information space, the tribal sign of any space is manifested - the unity of discontinuous and continuous. Continuity is provided by the constant communication process of people's communication, the ability to render information from the individual to the individual, from generation to generation. Communicativeness of the information space, its discreteness, which is due to the scattering of information and its distribution, have become the conditions for strengthening the information space. The disappearance of information at one point, through its movement and / or distribution, preserves information at other points of space, in which the information thesauri of other individuals operate. It is speculative, i.e. abstract, it is possible to reproduce the original information space, which consisted of a set of points (individual thesauri); its extent was measured by the possibility of the direct rendering of an information message to a certain distance both verbal and non-verbal / pre-verbal. The limitations in the extent of the information space are also related to the time that is necessary for rendering information, i.e. with the speed of rendering the information message from the individual to the individual.

The information thesaurus, as an independent and self-sufficient element for the emergence of an information space, can exist autonomously. However, this status cannot be prolonged. Then the individual has a space deficit.*The deficit of space* is often *overcomeby the expansion* of the cognitive and / or interpersonal space. The need for interpersonal and then for social information space arises in the process of individuals' joint activity. In any society of any scale, there is an objective need for sharing knowledge about the objective reality reflected by individual consciousness, so individuals belonging to this or that society start using information resources together.

Human civilization contributes to activity differentiation and accustoms the person to planned and ordered joint actions [6]. Leaders of the clans and tribes, the system of traditions, prescriptions and taboos controlled the human community and, undoubtedly, could influence the formation of the language and information thesauri, i.e. information resources; the ways of rendering them, and thus the quality of the information space of the society. Thus, the information space has a prominent social aspect and can be interpreted as *the relationship between people and their communities about information resources*. Hence, we can conclude: the evolution of the information space increases the importance of the managerial component of the information space because the manager is the most vivid carrier of properties and meanings that are common to the whole society.

The information space is *a non-additive whole*, it does not only inherit the properties of its original elements



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- space and information - but also, being a new phenomenon, it has its characteristics. In our opinion, these properties are the extent, volume and density. The *extent* of the information space can be characterized by the distance at which the necessary information resources are available to the individual. According to the encyclopaedical dictionary, the concept of "*volume*"can be defined as "the general limit of inscribed bodies." Concerning the information space, this concept can *characterize* the number of information resources included in the information space of one or another extent, *i.e. the number of available information resources*. The concept of "*density*" in mathematics is the inverse of volume. Concerning the information space, the concept of "density" can help determine the *saturation* of an information space with *information resources*. This characteristic can be derived in the information space with a certain extent while considering the ratio of the number of *information resources regarding the creators of information resources or regarding their consumers*. Thus, we have to talk about *different types of information space density*: by the number of information creators and by the number of information consumers.

The introduction of qualitative characteristics of the information space through the concepts of *"extent"*, *"volume"* and *"density"* shall allow us to develop quantitative indicators of these characteristics in future and equip researchers of the information space and information space practitioners with new tools for assessing the development of a particular information space; but it will be possible only due to specially developed software programs. The introduction of the coefficients of extent, volume and density shall allow us to use the tools of comparative analysis regarding different kinds of information space.

All the problems stated in the article are considered from the author's perspective. Most aspects of the consideration of the phenomenon of "information space" were proposed for the first time, and reflected on the general scientific and philosophical approaches.

We were able to speculatively reproduce the genesis and evolution of the information space, suggest the basis for differentiation and outline its types, as well as reveal its main characteristics and consider the content and scope of the concept of "information space". The article suggests approaches to perceiving the essence of this phenomenon. However, the essential definition is not formulated. Moreover, the levels of the information space and the forms for ensuring its integrity are not considered. The role and ability of the state to influence the maintenance of its integrity is not revealed. All these new aspects can be considered in following articles.

Further study of the phenomenon of "information space" involves formulating an essential description of the phenomenon and concept of "information space", examining the levels and ways of ensuring its integrity, and determining the role of the state in achieving its unity.

## 5. Conclusion

The aims and objectives specified in the introduction have been achieved, and it is important to continue publishing research about the phenomenon of "information space".

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ARTICLE

# SDWAN (Software Defined-WAN) Network Engineering and Project Management

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ABSTRACT

Many organizations are struggling to provide high bandwidth and reliable internet connectivity at their branch offices and business locations and getting the most out of their operational expense. The need for internet connectivity at any branch offices and business locations is not a luxury anymore but is a necessity. Let us try to understand how to plan and document the SDWAN (Software Defined- Wide Area Network) implementation in an organization. We will try to understand why it is essential to implement the new technology instead of investing in the existing MPLS (Multi-Protocol label switching) by taking an example of a retail organization. **Methods**: This project/research was performed using the abilities of Software Defined Network Technology and options available in MPLS (Multi-Protocol Label Switching). The Technical Project management principles were adopted as per PMI (Project Management Institute) waterfall methodology. **Results/ Conclusion**: SDWAN technology provides an effective replacement of MPLS network connection for providing WAN connectivity for our office locations. It is essential to follow a documented process for appropriate vendor selection based on the available features and other listed attributes in the article. To be successful in the implementation it is essential to perform a POC (Proof of Concept) in a controlled environment and validate results. SDWAN provides better network performance and improves reliability as the links operate in active-active function.

## 1. Introduction

In a business location, a retailer has to perform several transactions, and there is a need for reliable high-bandwidth internet circuit. In the absence of a high-speed internet connection, many locations may report slow internet performance as they may be running on a single high-cost low-bandwidth circuit. This initiative targets to deploy SDWAN technology at all the business locations. IT Network engineering team will be leading this initiative but as this is a cross-functional project so we will need help from different teams like IT Operations for Server and Storage requirements, Business Support for coordination with Business Associates, Network Administrator and Onsite Tech support team who will be responsible for device installation at all galleries. In addition to these stakeholders, we need to have a dedicated Project Manager (PM) to monitor the overall progress of the project, who will coordinate with COO for any budgetary issues and with VP - Infrastructure to allocate necessary organizational resources. The designated PM will work closely

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with Director Project Management Office to ensure the scheduled tasks for this project do not interfere with the projects in other areas of the business as the company has multiple projects going on at the same time. This Project is divided into four phases Design, Initial Implementation, Rollout, and Project Closure. We will estimate the average internet bandwidth upgrade and percentage increase in network and hardware reliability by reviewing the incident data post-upgrade to calculate the overall success of the project.

## 2. Needs Analysis for Project Design and Development

### 2.1 Problem

Let us assume that the company's e-commerce environment is hosted on a private cloud in a data center located in San Diego, California, and the organization is using Akamai as its CDN (Content Delivery Network) provider. The associate working in Business locations with the customers raises around seventy percent of orders. The Business associate can provide the customers with various options to customize their order depending on their preference. The associate needs to browse the organization's website and review different available options for the products with various features and attributes. The organization's website is full of high-resolution images that provide in-depth clarity to the content. In order to serve this requirement, there is a need for high-bandwidth and a reliable internet circuit.

Most of the business locations, especially bigger ones, have started reporting slow internet performance mostly in peak hours. On a few occasions, if there is an issue with the internet circuit, the internet connectivity of the business location goes down completely, and they cannot raise any orders. All these issues are causing a significant business loss as the locations are completely dependent on internet connectivity to perform their business.

### 2.2 Cause

Below factors are contributing to the poor network performance and causing unreliable network connection at all of the business locations and branch offices.

(1) Most of the Business locations have a high-cost low-bandwidth Private WAN (Wide Area Network) circuit. This circuit is very reliable but does not solve the increasing demand for high-bandwidth.

(2) Many Business locations are just operating on a single Private WAN circuit. Very few locations have a reliable secondary circuit.

(3) The Business's locations with dual circuits cannot utilize bandwidths effectively, as due to technical limitations; they are operating on Active/Passive mode. (Only one circuit can be utilized at one time).

### 2.3 Problem Impact

The impact of this problem is widespread and may affect multiple stakeholders. Please read below to find out how it can affect various stakeholders in an organization.

#### 2.3.1 COO (Chief of Operations)

COO is continuously getting reports of frequent internet outages at various retail locations. Business Leadership has reported that it is getting extremely difficult to perform a business transaction using existing Network Infrastructure. He is not only worried about business loss but also about brand value.

#### 2.3.2 VP (Vice President) - Infrastructure

Vice President - IT is seeing many incident tickets for poor Network performance from multiple locations in daily incident reports. He is aware that his team is not able to provide a timely resolution for all the reported incidents due to high incident counts and technical limitations. He is under a lot of pressure to provide a permanent fix to this problem.

#### 2.3.3 Network

The Network team is completely occupied in providing temporary fixes to a large number of issues that are being reported to them on a daily basis. Due to the heavy workload, they are not able to provide resolution to all the incidents as per agreed SLAs.

#### 2.3.4 IT Operations (IT Ops)

IT Operations team is observing their monitoring and incident management tool resources are completely occupied in managing the daily alert and incident counts. In order to manage the daily operational needs, they have to work extra hours almost on a daily basis.

#### 2.3.5 Business Support

The Business Support team is helping in communicating with the gallery associates and with the Network Administrators. They have to work extra hours as the ticket count is very high, and a lot of incidents are repetitive. It is due to these large number incidents Business Support team is not able to meet its response and resolution time on not only on slow internet response



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issues but also on other types of queries.

### 2.3.6 Business Associates

Business Associates are not able to serve their customers at the locations. In order to provide different options to the customer for any type of product, the associate has to look at the organization's website to refer to various attributes of the product. Many times when the internet is slow, the associates may struggle to provide these options, and when the internet is completely down, they cannot even raise an order in real-time.

### 2.4 Technology Trend

In the last few years, we have observed massive shifts in the way infrastructure and applications are built, managed, and deployed. Fueled by innovation in cloud infrastructure, new application design technologies, and pervasive low-cost Internet connectivity, seemingly anyone can deploy an entire infrastructure on a public cloud in minutes or take advantage of Software-as-a-Service (SaaS) offerings for a variety of what were once very expensive application suites that were historically deployed in a data center on expensive servers and storage. Business applications are becoming more involved, complex, and rich in content, driven by innovative experiences created in global scale consumer applications.

Software-defined WAN (SD-WAN) claims to provide a solution for these issues by allowing the user to define policies for how application traffic is forwarded. With SD-WAN, policies can be defined to specify which WAN links can be used for which applications, allowing the user to enjoy transport-agnostic connectivity amongst sites, WAN high availability for the remote office, and the cost benefits of deploying broadband Internet to reduce or eliminate private MPLS WAN links. The dirty secret for most SD-WAN vendors is that their architecture is built using some form of a packet routing or packet-processing engine. While SD-WAN functionality on the surface seems to be a natural evolution of packet routing and packet processing, packet-based systems are not equipped to understand today's applications given how both application complexity and content richness have increased, and HTTPS has become the de facto transport, which is rendered completely opaque by TLS. Packet-based systems are fundamentally unable to look at application-level transactions across multiple connections using both discrete data points and heuristics to accurately identify and understand the applications in use and how they are performing with the current connection.

AppFabric is a radically new approach to networking. With AppFabric, policies are defined by business intent for performance, security, and compliance: [2]

Performance - specify the performance and resources required to support positive user experience, and handle flows according to actual performance metrics of the application itself rather than the packet and link metrics.

Security - define the security perimeter for the remote offices and which applications are allowed to traverse the network boundary using detection of the actual application rather than IP addresses and ports.

Compliance - specify the WAN paths that the application flows are allowed to take and make forwarding decisions accordingly.

The most important compliance to follow for the retail organization is PCI. Any organization that handles any type of payment card data, should meet the Payment Card Industry (PCI) Compliance regulations. In order to ensure the new SDWAN partner is PCI compliant, we can add this as one of our requirements in the vendor selection criteria.

To ensure both the organizations are following the laws, we can agree on a mutual Non-Disclosure Agreement (NDA) before we start any discussions and share any company information.

Once a vendor has been finalized, the organization should sign a Mutual Service Agreement (MSA) and will execute an SOW (Statement of Works) documents that will clearly state all the services along with their SLAs (Service Level Agreement that the chosen partner will provide to the organization. The MSA will also have a clause that will ensure that the vendor is following all the industry standards to provide quality service to the customer.

## 3. Cost Analysis for Project Design and Development

Please refer below Cost Analysis for developing, installing, and supporting an SDWAN appliance at a location. In order to justify the investment (project cost), we have also put together some data on how much time we are spending on the support of maintenance of existing network infrastructure and incidents that are occurring due to the bandwidth and technology limitations. It is also important to make a note of the financial loss we have to suffer in case of an internet outage at a location. A team can use below sheet for reference (cost will vary depending on the location and business functions).

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**Table 1.** Cost - Benefit Analysis of using SDWAN as Inter-net Appliance at a location

| Projects Costs per Business Location | Amount |
|---|---|
| Hardware | |
| Data Center Hub - Product Design and Development | -- |
| Site Hardware | -- |
| Software & Licenses | -- |
| Support ( May be Included in License) | -- |
| Internal - Labor ( $XX/ hour)-Installation 2 hour per location | -- |
| External - Labor ($XX/ hour)-Installation 4 hour per location | -- |
| Internet Connection 1-Monthly Recurring Charge per location | -- |
| Internet Connection 2-Monthly Recurring Charge per location | -- |
| | |
| Total Capital Expense for each location ( Only First Year) | -- |
| Total Operational Expense for each location | -- |
| | |
| **Current Costs ( Project Cost Justification)** | |
| Current Site Hardware Support | -- |
| Current Data Center Hardware Support & Maintenance | -- |
| Internal - Labor ( $XX/ hour) - To solve Incidents | -- |
| External - Labor ($XX/ hour) - For Technician | -- |
| Internet Connection 1 | -- |
| Loss in revenue due to internet outage (per hour) | |
| Big Business Locations | -- |
| Small Business Locations | -- |
| | |
| Total Operational Expense | -- |
| Revenue Loss per hour for each Business Location | -- |

***Cost Justification***

In order to solve the increasing demand for more internet bandwidth at all our locations, as an IT department, we completely understand that there is a demand for high bandwidth circuits at all of our retail locations, but at the same time, we need to increase reliability. The monthly re-occurring cost (MRC) of existing MPLS (Multiprotocol label switching) connections is already on a higher side, and the high bandwidth MPLS circuit is completely out of our operational budget. In addition to this, with existing MPLS network architecture, we are backhauling all internet traffic to our Datacenter that further introduces more latency due to round-trip time.

The existing technology using traditional network architecture is, for sure, not able to provide a solution that can solve our needs and still be affordable. The time has come to explore the capabilities of the SDWAN (Software Defined - Wide Area Network) solution. According to Wikipedia (n.d.), an SD-WAN simplifies the management and operation of a WAN by decoupling (separating) the networking hardware from its control mechanism [5]. This concept is similar to how software-defined networking implements virtualization technology to improve data center management and operation.

A key application of an SD-WAN is to allow companies to build higher-performance WANs using lower-cost and commercially available Internet access, enabling businesses to partially or wholly replace more expensive private WAN connection technologies such as MPLS

According to Imagineiti (n.d.), the organization that is supported by internal IT staff or vendors who use a break-fix methodology will generally pay the following hourly rates [4] :

Individual Techs :$65 to $100 per hour

Vendor Support :$75 to $125 per hour

It should become very clear from the above Cost-Benefit Analysis that the organization is not only spending huge amounts in supporting the existing technology, but they are not getting any benefits in return. The truth is due to the current network setup, and the organization is not only losing a lot in revenues but also our customer confidence in our brand. It makes total sense to invest in the new technology and avoid these outages so that we can run our business smoothly. The new technology architecture is centrally managed through a cloud-based controller and needs minimum operational expenditure once it is implemented.

## 4. Risk Assessment

### 4.1 Qualitative Risk Analysis

Please refer to the Qualitative risk analysis of the SD-WAN implementation project.

**Table 2.** Qualitative risk analysis of the SD-WAN implementation project

| Risk | Description | Qualitative Analysis | |
|---|---|---|---|
| | | **Likelihood** | **Rating** |
| **Device Stability** | We will be installing new hardware in our network that we have not tested. We are relying on SDWAN partner to ensure device stability and performance | Moderate | 3 |



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| | | | |
|---|---|---|---|
| **Technology Reliability** | SDWAN is a new technology which we haven't used in our network architecture so far, and we don't have any in-house expertise to support the technology | Moderate | 3 |
| **Technology Adaption** | The new SDWAN is completely software- driven, and we don't know how other enterprise application will be affected | Low | 2 |
| **Software Vulnerabilities** | The new technology may have introduced new security vulnerabilities to our network infrastructure | Moderate | 3 |
| **Hardware & Software Support** | The new SDWAN partner may not be able to provide the required support as per our expectations | Very Low | 1 |
| **Aggressive Schedule** | In order to solve the issue we need to deploy the new hardware quickly, and it may impact existing location operations | High | 4 |
| **Resource Crunch** | As we are planning to install the new appliance at a very fast pace, we may run short of resources if we encounter any issue during the deployment | Very High | 5 |

In this analysis, we have used a relative scale as per below definition:

**Table 3.** Relative scale

| Rating | Likelihood | Description |
|---|---|---|
| 1 | Very Low | Highly unlikely to occur. May occur in exceptional situations. |
| 2 | Low | Most likely will not occur. Infrequent occurrence in past projects |
| 3 | Moderate | Possible to occur |
| 4 | High | Likely to occur. Has occurred in past projects |
| 5 | Very High | Highly likely to occur. Has occurred in past projects and conditions exist for it to occur on this project |

## 4.2 Quantitative Risk Analysis

Please refer to the Quantitative risk analysis of the SD-WAN implementation project.

**Table 4.** Quantitative risk analysis of the SD-WAN implementation project

| Risk | Description | Quantitative Analysis | | |
|---|---|---|---|---|
| | | **Probability of Occurrence** | **Impact (Cost Analysis)** | |
| | | | **Cost** | **Schedule** |
| **Device Stability** | We will be installing new hardware in our network that we have not tested. We are relying on SDWAN partner to ensure device stability and performance | 35 -50% | >20% increase in development Cost | 1-2 weeks delay |
| **Technology Reliability** | SDWAN is a new technology which we haven't used in our network architecture so far, and we don't have any in-house expertise to support the technology | 35 -50% | >20% increase in development Cost | 1-2 weeks delay |
| **Technology Adaption** | The new SDWAN is completely software-driven, and we don't know how other enterprise application will be affected | 10-25% | 5-10% increase, to deploy more time and resources for testing | 1-2 weeks delay |
| **Software Vulnerabilities** | The new technology may have introduced new security vulnerabilities to our network infrastructure | 10-25% | 5-10% increase, to deploy more time and resources for testing | 1-2 weeks delay |
| **Hardware & Software Support** | The new SDWAN partner may not be able to provide the required support as per our expectations | 5-10% | < 5% increase to deploy more resources for support | < 1-week delay |
| **Aggressive Schedule** | In order to solve the issue we need to deploy the new hardware quickly, and it may impact existing Business operations | 50-60% | >30% increase to deploy more resources | >2 weeks delay |
| **Resource Crunch** | As we are planning to install the new appliance at a very fast pace, we may run short of resources if we encounter any issue during the deployment | 60-80% | >30% increase to deploy more resources | >2 weeks delay |

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### 4.3 Cost/Benefit Analysis

We have observed in the previous section where we performed the Cost/Benefit Analysis for the SDWAN implementation project that if we continue to use existing technology to provide network connectivity at our Business locations we may have to suffer around $XX in revenue loss. We are also spending around $XX in support and maintenance for each location. We are planning to spend around $XX per location to implement the new technology, and we will only spend around $XX in support and maintenance per location, which is a significant reduction in the support cost.

It will become clear by the analysis results that investing in new technology is beneficial for the company, as it will significantly improve internet reliability and network performance at our locations. All the reported risks can be mitigated by taking some proactive measures.

This initiative will help the organization to improve in below areas:

(1) Internet bandwidth upgrade for all branch offices and business locations.

(2) The use of SDWAN technology will provide effective utilization of dual internet circuits.

(3) SDWAN technology will improve the reliability of internet connectivity at all the business locations by the easy transition from one internet circuit to the other in case of any failures.

(4) We can achieve a lower network downtime in case of any hardware failures caused by Primary network hardware (Router).

(5) The new SDWAN platform is completely based on software-based routing which significantly reduces the time for network management

(6) The network policies for all the Branch Offices and Business Locations will be centrally managed through a cloud-based controller.

### 4.4 Risk Register

**Table 5.** Risk Register

| Asset | Threat/Vulnerability | Existing Controls | Likelihood | Consequence | Level of Risk | Risk Priority |
|---|---|---|---|---|---|---|
| **SDWAN Hardware** | Threat | Protection Clause in agreement .The new technology will be implemented only after QA (Quality Analysis) testing | Possible | Moderate | Medium | Level 2 |
| **SDWAN Software** | Threat | Protection Clause in agreement .The new technology will be implemented only after QA (Quality Analysis) testing | Possible | Moderate | Medium | Level 2 |
| **SDWAN Software** | Vulnerability | Protection Clause in agreement. The new technology will be implemented only after running vulnerability scans and reviewing support documentation | Rare | Minor | Low | Level 4 |
| **Resources ( People)** | Threat | Onsite Tech will provide additional support as and when needed | Almost Certain | Major | Extreme | Level 1 |
| **Budget** | Threat | Project Manager to include buffer to accommodate any extra expenditure | Almost Certain | Major | High | Level 1 |
| **Revenue** | Threat | Hardware should be deployed in the production only after significant testing to minimize any outages in production environment | Possible | Minor | High | Level 3 |

### 4.5 Risk Mitigation

**Table 6.** Risk Mitigation

| Risk | Description | Mitigation |
|---|---|---|
| **Device Stability** | We will be installing new hardware in our network that we have not tested. We are relying on SDWAN partner to ensure device stability and performance | The new hardware will be thoroughly tested in the QA environment before we deploy it in the production network |
| **Technology Reliability** | SDWAN is a new technology which we haven't used in our network architecture so far, and we don't have any in-house expertise to support the technology | The new technology will be tested in the QA environments using different scenarios before we deploy to the production network |



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| | | |
|---|---|---|
| **Technology Adaption** | The new SDWAN is completely software-driven and we don't know how other enterprise application will be affected | Application compatibility with other enterprise applications will be tested in QA environments using different scenarios |
| **Software Vulnerabilities** | The new technology may have introduced new security vulnerabilities to our network infrastructure | The new technology will be implemented only after running vulnerability scans and reviewing support documentation |
| **Hardware & Software Support** | The new SDWAN partner may not be able to provide the required support as per our expectations | The technology partner has to follow the agreed SLA as per the service agreement. There will be significant penalties in case of any SLA breach. |
| Aggressive Schedule | In order to solve the issue we need to deploy the new hardware quickly, and it may impact existing Business operations | Onsite Tech will provide additional support as and when needed to ensure it doesn't impact existing operations. In case any outage in involved, that work will be performed in off- hours. |
| **Resource Crunch** | As we are planning to install the new appliance at a very fast pace, we may run short of resources if we encounter any issue during the deployment | Onsite Tech will provide additional support as and when needed |

## 5. Justification

In our business scenario, let us assume around seventy percent of orders are raised by the Business associate working in the business locations with the customers. The Business associate can provide the customers with various options to customize their order depending on their preference. The associate needs to browse the organization's website and review different available options for the products along with various features. The website is full of high-resolution images that provide in-depth clarity to the content

Most of the Business locations have started reporting slow internet performance, mostly in peak hours. On a few occasions, if there is an issue with the internet circuit the internet, connectivity of these locations goes down completely, and they cannot raise any orders. All these issues are causing a significant business loss, as the business locations are completely dependent on the internet connectivity to perform their business.

In the cost-benefit analysis, we observed that we are paying a lot of money for the current low bandwidth T1 (MPLS) circuit. In order to solve the increasing demand for more internet bandwidth at all our locations, as an IT department, we completely understand that there is a demand for high bandwidth circuits at all of our retail locations, but at the same time, we need to increase reliability. The monthly re-occurring cost (MRC) of existing MPLS (Multiprotocol label switching) connections is already on a higher side, and the high bandwidth MPLS circuit is completely out of our operational budget. In addition to this, with the existing MPLS network architecture, we are backhauling all internet traffic to our Datacenter that fur-ther introduces more latency due to round-trip time.

The existing technology using traditional network architecture is, for sure, not able to provide a solution that can solve our needs and still be affordable. The time has come to explore the capabilities of the SDWAN (Software Defined - Wide Area Network) solution. According to Wikipedia (n.d.), an SD-WAN simplifies the management and operation of a WAN by decoupling (separating) the networking hardware from its control mechanism. This concept is similar to how software-defined networking implements virtualization technology to improve data center management and operation.

A key application of an SD-WAN is to allow companies to build higher-performance WANs using lower-cost and commercially available Internet access, enabling businesses to partially or wholly replace more expensive private WAN connection technologies such as MPLS.

SDWAN is a new technology of network management that provides the following capabilities:

(1) Support and use of multiple connection types (active/active).

(2) Dynamic path selection for applications.

(3) A simple interface for managing the WAN policies.

Fundamental benefits of these capabilities are lower WAN costs, better application performance/reliability, and far less complex centralized control function for provisioning and management.

I believe that investing in SD-WAN technology is beneficial for the organization, as it will significantly improve internet reliability and network performance at our locations. All the reported risks can be mitigated by taking some proactive measures.

## 6. Project Management Plan

### 6.1 Resources

IT Network engineering team will be leading this initiative, but we will need help from different teams to complete this project. We will need help from below internal teams:

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(1) IT Network Engineering
(2) Network Architect
(3) Network Administrators

### 6.2 Justification: IT Network Engineering

Network Architect will work closely with the SDWAN technology partner to design the network. Network administrators will be responsible for switch and appliance configurations. The network team will work as per the agreed schedule tasks and implementation plan:

(1) IT Operations (Server & Storage)
(2) Server Administrator
(3) Storage and Backup Administrator

### 6.3 Justification: IT Operations Team

IT Operations team will provide necessary compute storage for hosting the application in the Datacenter. Server Administrator will work on integrating the SDWAN platform with other enterprise applications like OKTA for single sign-on or monitoring tools like Solarwinds for alert monitoring purposes. Storage and Backup Administrator will provide the necessary storage for the servers and will be responsible for adding any servers to backup policy.

(1) Business Support
(2) Technical Support Analyst
(3) Support Center Leader

### 6.4 Justification: Business Support

The Technical Support Analyst will work closely with the Network Team and Project Manager for the installation of the SDWAN hardware in all galleries will help in coordinating any tasks with the project manager and will also collect feedback from the Business associates. Support Center Leader will be responsible for providing the necessary resources to the support staff and will conduct training on the new technology.

(1) Project Management Office
(2) Project Manager
(3) Director PMO

### 6.5 Justification: Project Management

The Project Manager will be responsible for the overall progress of the project. He will be responsible for preparing the Project Plan, tasks scheduling, and coordinating resources. He will also maintain the project budget and will regularly update on the overall progress to all the project stakeholders. He will also review the overall Project portfolio for the organization along with the Director PMO to ensure any scheduled tasks doesn't clash with the other major activities going on in other business areas.

In order to provide additional help and support below partners will be helping us in the design and implementation of the project:

Onsite Tech

### 6.6 Justification: Onsite Tech

The Onsite Tech support team will be responsible for providing the necessary resources and tools for the installation of SDWAN hardware at all the Branch Offices and outlet locations. They will provide the necessary Hands & Feet support to the Network administrator who will be making the required configuration changes remotely:

SDWAN Technology Partner

### 6.7 Justification: SDWAN Technology Partner

The SDWAN partner will work closely with the Network Architect during the initial network design. They will also provide support to the Project Manager and Network Administrator for preparing any training materials or making decisions on any configuration changes:

Business Associates

### 6.8 Justification: Business Associates

A Business associate will provide feedback on the overall hardware installation service during implementation and on network performance improvement after installation.

He will also provide any special access or permissions required for the installation of a new internet circuit or any hardware device.

In addition to the above-listed teams/resources, the Project Manager will also have below Stakeholders in this project.

***COO (Chief of Operations)***

COO will approve the budget allocated to the project and will be responsible for providing any financial resources for the completion of the project. The PM and VP-Infrastructure will update COO on the overall progress of the project. [1]

***VP (Vice President) - Infrastructure***

The VP Infrastructure will work closely with all IT teams and PM to allocate the necessary organizational resources required for project task completion. He will also approve any changes required in the network and application architecture that may be necessary to complete the project.

### 6.9 Resources Utilization Plan

Please refer below matrix to review resource utilization in each phase:



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**Table 7.** Resource utilization in each phase

| Skills | Project Phases (Estimated hours) | | | |
|---|---|---|---|---|
| | SDWAN Design | Initial Implementation | Roll Out | Project Closure |
| **Phase Duration** | 2 weeks | 1 week | 2-3 weeks | 1-2 weeks |
| **Project Manager** | 40 | 30 | 30 | 70 |
| **Network Architect** | 60 | 30 | 10 | 40 |
| **Network Administrator** | 20 | 50 | 200 | 50 |
| **Business Support** | 10 | 20 | 100 | 60 |
| **IT Operations** | 10 | 20 | 70 | 20 |
| **SDWAN Partner** | 30 | 20 | 100 | 50 |

In addition to the above resource estimate, we anticipate that we will need support from Onsite Tech - 4 hours per store.

The leadership team like Branch Office Leader will be engaged as per the requirements for coordinating resources.

### 6.10 Existing Gaps that Current Project Plan will Fulfill

(1) Ensure IT Infrastructure Requirements are captured at the right stage of the Project.

(2) All requirements are captured for different tracks (Network, Servers, End-User Computing )

(3) Ensure the right product is selected to support the application and business, which is essential to support the growth for the near future.

(4) Ensure the right vendors are selected with appropriate experience/expertise in the necessary field.

(5) All Stakeholders have adequate visibility from the initial stage, and they can help in scope determination/ make appropriate changes.

***What all is in scope with this new Project Implementation approach:***

(1) Any new initiative that is driven by the Application or Infrastructure team requiring any IT infrastructure changes with 50+ hours of cross-functional project work.

(2) Different teams should review any new implementation that will significantly influence the current operations before being implemented.

***How this will help in other active or upcoming projects:***

(1) Provides adequate time to the IT infrastructure team to size the infrastructure appropriately.

(2) Helps IT Network and Operations team in choosing the correct vendor/technology as they have the complete picture and feedback from cross-functional team.

(3) IT Support Staff is well prepared to support the new technology and processes once the handover is given to them.

## 7. Project Plan in Detail

### 7.1 Scope

The goal of the project is to improve network performance and reliability at all of our retail locations, and we plan to achieve this goal by fulfilling the below objectives.

(1) Finalize an SDWAN Technology partner.

(2) Integrate new technology with our enterprise network

(3) Deploy this technology in all of our locations

(4) Install dual high bandwidth direct internet access circuits at all the locations.

(5) Effectively utilize dual internet connections in Active-Active configuration.

### 7.2 Assumptions

(1) Architecture & Design: SDWAN partner will be able to successfully integrate new technology with our existing production network.

(2) Infrastructure: Our existing infrastructure at Branch Offices and Data Center will be able to host the new hardware.

(3) Technology: Our existing enterprise applications, like monitoring tools and communication systems, will be able to integrate with the new technology.

(4) Business: Site Operations/Property management will allow relevant access to the Branch Offices/devices to perform necessary changes.

(5) Methodology & Standards: Our Project Management methodology will help in executing various phases of the project smoothly.

### 7.3 Project Phases

Please refer below to review various phases in the project and the major objectives of each phase.

#### 7.3.1 SDWAN Design

(1) Identify what SDWAN has to offer

(2) Research available SDWAN vendors

(3) Finalize an SDWAN Vendor

(4) Shortlist a vendor and perform a POC

#### 7.3.2 Initial Implementation

(1) Implement the solution in the first location and evaluate results

(2) Implement solution in five more locations

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### 7.3.3 Roll out

(1) Implement final solution in remaining Branch Offices and outlet locations

(2) Review results with the Site operations team and Management

(3) Prepare Training and Documentation

### 7.3.4 Project Closure

(1) Conduct Training for Operations and Support Team

(2) Handover to Operations

(3) Update Integrations with Incident Management Tool

(4) Prepare Project Closure Documentation

## 7.4 Timelines

Project Launch: Date

**Table 8.** Timelines

| Duration | Week1 | Week2 | Week3 | Week4 | Week5 | Week6 | Week7 |
|---|---|---|---|---|---|---|---|
| Phases | | | | | | | |
| SDWAN Design | | | | | | | |
| Identify what SDWAN has to offer | | | | | | | |
| Research available SDWAN vendors | | | | | | | |
| Finalize an SDWAN Vendor | | | | | | | |
| Shortlist a vendor and perform a POC | | | | | | | |
| Initial Implementation | | | | | | | |
| Implement the solution in the first location and evaluate results | | | | | | | |
| Implement the solution in five more locations | | | | | | | |
| Roll out | | | | | | | |
| Implement the final solution in remaining Branch Offices and locations | | | | | | | |
| Review results with the Business Operations team and Management | | | | | | | |
| Prepare Training and Documentation | | | | | | | |
| Project Closure | | | | | | | |
| Conduct Training for Operations and Support Team | | | | | | | |
| Handover to Operations | | | | | | | |
| Update Integrations with Incident Management Tool | | | | | | | |
| Prepare Project Closure Documentation | | | | | | | |

## 7.5 Important Milestones

(1) Finalize an SDWAN Vendor

(2) Finalize Network Design with SDWAN Vendor

(3) Implement SDWAN technology in the first location

(4) Review performance results with Project team and management

(5) Approval to proceed with the rollout

(6) Implement SDWAN technology in all the office locations

(7) Handover to Operations

## 7.6 Project Launch Details

According to Aston, B (2016), the project kick-off meeting is the first meeting between a project team and the sponsor of a project when kicking off a new project. We will be inviting the Executives and Leaders from all the relevant business areas to brief them on the project scope, objectives, and timelines [1].

We will also schedule a deep dive meeting with all the stakeholders involved to introduce the team, understand the project background, understand what success looks like, understand what needs to be done, and agree on how to work together effectively.

We will also schedule a meeting with Onsite Tech to review their responsibilities, and this meeting is an opportunity to get the key information they need to succeed and demonstrate their enthusiasm and understanding of the project.

The Project Manager will schedule regular meetings to keep the team members and stakeholders up to date on the progress. He will also work with IT Operations to create a distribution list of all the team members involved and will send weekly updates.IT Operations team is also planning to create a new #slack channel for collaboration purposes.

## 7.7 Project Strategy- Explanation

In our Project Management methodology, we are primarily managing three areas to achieve the desired project goals.

(1) People

(2) Process

(3) Technology

(1) People

During the SDWAN Design Phase, we are planning to involve all the stakeholders from the beginning of the project. The leadership and the technical teams will be involved in the product demonstration and vendor selection process. The collective feedback will be gathered from the team members, and they will be asked to rate the tech-



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nology and product on a Google form. This will give all the project members an opportunity to provide feedback and will help the project team to make the right decision. During the implementation phase, we are planning to install the new appliance at a very fast pace, and we may run short of resources if we encounter any issue during the deployment, to mitigate that risk we have partnered with Onsite Tech to provide additional resources.

(2) Process:

This project involves the implementation of new technology in the organization, and we need to have thorough process checks at every stage to make sure we are giving a tried and tested input to the next processes in the task list. In order to ensure the technology is well received in the production network, the technical and the SDWAN partner will work very closely during the SDWAN Design and Initial Implementation phase. The testing team will follow a complete checklist of expected outcomes for various scenarios and will document the same. The IT Operations team will ensure that the new software integrates with the existing enterprise applications like monitoring tools and communication systems before it is deployed in the production environment. The changes to the production environment will be performed only in off- hours, and all of the production changes will have to go through a change control process.

(3) Technology:

In order to solve the increasing demand for more internet bandwidth at all our locations, as an IT department, we completely understand that there is a demand for high bandwidth circuits at all of our Business locations, but at the same time, we need to increase reliability. The monthly re-occurring cost (MRC) of existing MPLS connections is already on a higher side and the high bandwidth MPLS circuits are completely out of our operational budget. In addition to this, with existing MPLS network architecture, we are backhauling all internet traffic to our Datacenter that further introduces more latency due to round-trip time. The existing technology using traditional network architecture is, for sure, not able to provide a solution that can solve our needs and still be affordable. The time has come to explore the capabilities of the SDWAN solution. According to Gartner (2015), SD-WAN is an emerging technology that offers several benefits compared with traditional, router-based WANs. Network Architects can achieve cost savings, increased agility, and simplification with SD-WAN [3].

## 7.8 Documentation Deliverables

(1) Non-Disclosure Agreements (NDA) with various SDWAN providers for technology review

(2) Master Service Agreement (MSA) with SDWAN partner

(3) Statement of Works (SOW) with SDWAN partner

(4) Project Plan

(5) Network Architecture showing SDWAN in the production network

(6) Application integration document

(7) SDWAN Hardware Installation Guide

(8) Organization's Network Topology including SDWAN

(9) SDWAN Network Administration Guide

(10) SDWAN Business Support Guide

## 7.9 Hardware and Software Deliverables

(1) SDWAN hardware installation in all retail locations

(2) Dual Direct Internet Access circuit installation at all locations

(3) Network Policy Configuration for SDWAN software

(4) Security Policy configuration for SDWAN software

## 7.10 Final Assessment Criteria

The overall success of the project will be evaluated based on the below criteria.

(1) Improvement in network performance after the implementation of the project.

(2) Ease of implementation of the new technology at the new sites.

(3) Ease of Network administration

(4) Reduction in network incidents after the final rollout

(5) Overall operational and process improvements

(6) Vulnerability reports on the hardware and software.

We will use below Metrics to measure the proposed and actual outcomes of the project.

**Table 9.** Measure the proposed and actual outcomes of the project

| Evaluations Area | Proposed % | Actual % | Business Feedback |
|---|---|---|---|
| Internet Bandwidth Upgrade | | | |
| Network Reliability | | | |
| Hardware Reliability | | | |
| Ease of Installation | | | |
| Ease of Access | | | |
| Network Management | | | |
| Security Policies Management | | | |
| Vendor Support | | | |

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The network performance will be measured using a tool that is an industry leader in performing a speed test provided by OOKLA. In order to measure the overall network performance and compare the pre and post-installation results, we will be using a renowned industry tool Solarwinds NPM (Network Performance Monitor). To measure incident ticket count and ease of administration using the incident resolution time matrix, we will be using the ServiceNow tool that is one of the most popular Cloud-based ticketing systems in the industry today. The organization should only select an SDWAN partner once he provides the supportive documentation that their product has passed the necessary security and health safety tests. The organization should plan to perform a vulnerability test once the product is installed in the first business location to ensure there are no new vulnerabilities discovered in the network.

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ARTICLE

# A Study on the Effects of Internal Heat Generation on the Thermal Performance of Solid and Porous Fins using Differential Transformation Method

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ABSTRACT

In this study, the impacts of internal heat generation on heat transfer enhancement of porous fin is theoretical investigated using differential transform method. The parametric studies reveal that porosity enhances the fin heat dissipating capacity but the internal heat generation decreases the heat enhancement capacity of extended surface. Also, it is established that when the internal heat parameter increases to some certain values, some negative effects are recorded where the fin stores heat rather than dissipating it. This scenario defeats the prime purpose of the cooling fin. Additionally, it is established in the present study that the limiting value of porosity parameter for thermal stability for the passive device increases as internal heat parameter increases. This shows that although the internal heat parameter can help assist higher range and value of thermal stability of the fin, it produces negative effect which greatly defeats the ultimate purpose of the fin. The results in the work will help in fin design for industrial applications where internal heat generation is involved.

## 1. Introduction

In many thermal systems, heat is excessive generated that might lead to thermal damage of the systems. Over the years, different active and passive methods have been adopted to dissipate the excessive heat from the thermal systems. Although fins have been used as extended surfaces heat transfer augmentation in most devices, the presence of pores in the fins further increases the heat enhancement capacity of the extended surfaces. In fact, the application of porous fin with certain number of pores may give same performance as convectional fin and save 100ϕ of the fin material [1]. Consequently, in some earlier works on extended surfaces, various studies have been put forward on the porous fins [1-9]. In recent times, different authors have adopted different techniques to study the heat transfer in porous fin [10-27]. However, a study on the effects of variable internal heat generation on the thermal performance of the solid and porous fins have not been addressed. Therefore, in this work, heat transfer analysis of porous fin with linear and non-linear variable internal heat generation using differential transform method is presented.

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## 2. Problem Formulation

Consider the flow of heat through a longitudinal rectangular porous fin that as shown in Figure1. Following the model assumptions in our previous studies [27], the thermal energy balance could be expressed

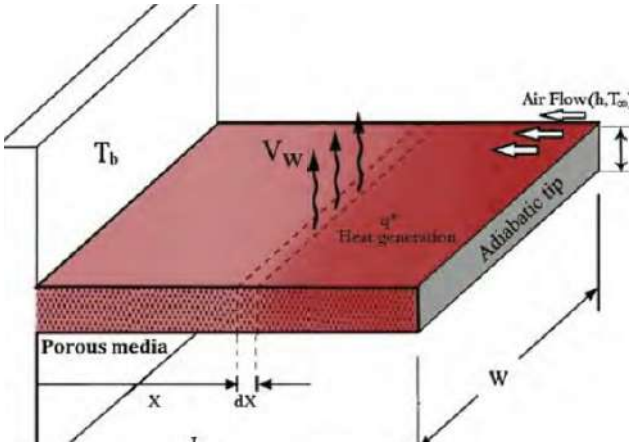


**Figure 1.** Schematic of a longitudinal rectangular porous fin with internal heat generation [18]

$$\frac{d^2T}{dx^2}-\frac{h(T-T_a)}{k_{eff,a}t}-\frac{\rho c_p\, g K\beta'(T-T_a)^2}{k_{eff,a}t\nu_f}+\frac{q(T)}{k_{eff,a}}=0 \tag{1}$$

where the boundary conditions of the fin are given as

$$\begin{aligned} &when \quad x=0, \quad T=T_b \\ &when \quad x=L, \quad \frac{dT}{dx}=0 \end{aligned} \tag{2}$$

The internal heat generation are temperature-dependent. Therefore, the linear and non-linear temperature-dependent internal heat generations are given by

$$q_{\text{int}}(T)=q_a[1+\psi(T-T_a)] \tag{3}$$

$$q_{\text{int}}(T)=q_a[1+\psi_1(T-T_a)+\psi_2(T-T_a)^2] \tag{4}$$

where T, $T_b$, $T_a$, $h_b$ g, $k_{eff}$ , q, t, v , $c_p$ ρ, L and w temperature of the fin, base temperature, ambient temperature, heat transfer coefficient at the base of the fin, gravity constant, effective thermal conductivity of the fin, internal heat generation, thickness of the fin, kinematic viscosity of fluid passing through porous fin, density of the fluid, length of the fin and width of the fin. respectively.

When Eqs. (3) and (4) are substituted, Eq. (1) becomes

For the linear temperature-dependent internal heat generation

$$\frac{d^2T}{dx^2}-\frac{h(T-T_a)}{k_{eff,a}t}-\frac{\rho c_p\, g K\beta'(T-T_a)^2}{k_{eff,a}t\nu_f}+\frac{q_a}{k_{eff,a}}[1+(T-T_a)]=0 \tag{5a}$$

For the nonlinear temperature-dependent internal heat generation

$$\frac{d^2T}{dx^2}-\frac{h(T-T_a)}{k_{eff,a}t}-\frac{\rho c_p\, g K\beta'(T-T_a)^2}{k_{eff,a}t\nu_f}+\frac{q_a}{k_{eff,a}}[1+\psi_1(T-T_a)+\psi_2(T-T_a)^2]=0 \tag{5b}$$

Using the following dimensionless parameters in Eq. (5a) and (5b);

$$X=\frac{x}{L},\quad \theta=\frac{T-T_a}{T_b-T_a},\quad Ra=Gr.\Pr=\left(\frac{\beta' gT_bt^3}{\nu_f^2}\right)\left(\frac{\rho c_p\nu_f}{k_{eff,a}}\right),\quad Da=\frac{K}{t^2},\quad Q=\frac{q_aA_c}{h_bP(T_b-T_a)},\quad M^2=\frac{hL^2}{k_{eff,a}t}$$

$$S_h=\left(\frac{\beta' g(T_b-T_a)t^3}{\nu_f^2}\right)\left(\frac{\rho c_p\nu_f K}{k_{eff,a}t^2}\right)\frac{(L/t)^2}{k_{eff,a}}=\frac{RaDa(L/t)^2}{k_{eff,a}},\quad \gamma=\psi(T_b-T_a),\quad \gamma_1=\psi_1(T_b-T_a),\quad \gamma_2=\psi_2(T_b-T_a) \tag{6}$$

Da, K, M, Q, Ra, $S_h$, γ and θ are Darcy number, permeability of the porous fin, dimensionless thermo-geometric parameter, dimensionless heat transfer rate per unit area, Rayleigh number, $_{\text{porosity}}$ parameter, dimensionless internal heat parameter and temperature, respectively.

The dimensionless forms of the Eqs. (5a) and (5b) are

For the linear temperature-dependent internal heat generation

$$\frac{d^2\theta}{dX^2}-M^2\theta-S_H\theta^2+M^2Q\gamma\theta+M^2Q=0 \tag{7a}$$

For the nonlinear temperature-dependent internal heat generation

$$\frac{d^2\theta}{dX^2}-M^2\theta-S_H\theta^2+M^2Q\gamma_1\theta+M^2Q\gamma_2\theta^2+M^2Q=0 \tag{7b}$$

The dimensionless boundary conditions are

$$\begin{aligned} &when \quad X=0, \quad \theta=1 \\ &when \quad X=1, \quad \frac{d\theta}{dX}=0 \end{aligned} \tag{8}$$

## 3. Method of Solution: Differential Transform Method

The nonlinearities in Eqs. (7a) and (7b) call for the use of an approximate analytical method or a numerical method. In this study, we use differential transformation method. The definition and the operational properties of the method can be found in our previous study [28]. The differential transformation of the Eq. (7a) are given as

For the linear temperature-dependent internal heat gen-



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eration is given as

$$(p+1)(p+2)\theta(p+2)-M^2\theta(p)-S_h\sum_{r=0}^{p}\theta(r)\theta(p-r)+M^2Q\gamma\theta(p)+M^2Q\delta(p)=0 \tag{13}$$

where

$$\theta(p+2)=\frac{M^2\theta(p)+S_h\sum_{r=0}^{p}\theta(r)\theta(p-r)-M^2Q\gamma\theta(p)-M^2Q\delta(p)}{(p+1)(p+2)} \tag{14}$$

With the boundary conditions,

$$\theta(0)=1,\quad \theta(1)=a,$$

We arrived at

$$\theta(2)=\frac{-M^2Q}{2}+\frac{S_h}{2}+\frac{M^2}{2}-\frac{M^2Q\gamma}{2}$$

$$\theta(3)=\frac{aS_h}{3}+\frac{M^2a}{6}-\frac{aM^2Q\gamma}{6}$$

$$\theta(4)=\frac{-S_hM^2Q\gamma}{8}-\frac{S_hM^2Q}{12}+\frac{S_h^2}{12}+\frac{S_hM^2}{8}-\frac{M^4Q\gamma}{12}+\frac{a^2S_h^2}{12}-\frac{M^4Q}{24}+\frac{M^4}{24}+\frac{M^4Q^2\gamma}{24}+\frac{M^4Q^2\gamma^2}{24}$$

$$\theta(5)=\frac{-S_haM^2Q}{20}-\frac{S_h^2a}{12}+\frac{S_haM^2}{12}-\frac{S_haM^2Q\gamma}{12}+\frac{aM^4}{120}-\frac{aM^4Q\gamma}{60}+\frac{M^4Q^2a\gamma^2}{120} \tag{15}$$

Therefore, from the definition

$$\theta(X)=1+aX+\left(\frac{S_h}{2}-\frac{M^2Q}{2}+\frac{M^2}{2}-\frac{M^2Q\gamma}{2}\right)X^2+\left(\frac{aS_h}{3}+\frac{M^2a}{6}-\frac{aM^2Q\gamma}{6}\right)X^3$$
$$+\left(\frac{S_hM^2}{8}-\frac{S_hM^2Q\gamma}{8}-\frac{S_hM^2Q}{12}+\frac{S_h^2}{12}-\frac{M^4Q\gamma}{12}+\frac{aS_h^2}{12}-\frac{M^4Q}{24}+\frac{M^4}{24}+\frac{M^4Q^2\gamma}{24}+\frac{M^4Q^2\gamma^2}{24}\right)X^4$$
$$+\left(\frac{S_h^2aM^2}{12}-\frac{S_haM^2Q}{20}-\frac{S_h^2a}{12}-\frac{S_haM^2Q\gamma}{12}+\frac{aM^4}{120}-\frac{aM^4Q\gamma}{60}+\frac{M^4Q^2a\gamma^2}{120}\right)X^5+\ldots. \tag{16}$$

For the nonlinear temperature-dependent internal heat generation is given as

$$(p+1)(p+2)\theta(p+2)-M^2\theta(p)-S_h\sum_{r=0}^{p}\theta(r)\theta(p-r)+M^2Q\gamma_1\theta(p)$$
$$+M^2Q\gamma_2\sum_{r=0}^{p}\theta(r)\theta(p-r)+M^2Q\delta(p)=0 \tag{17}$$

From which

$$\theta(p+2)=\frac{M^2\theta(p)+S_h\sum_{r=0}^{p}\theta(r)\theta(p-r)-M^2Q\gamma_2\sum_{r=0}^{p}\theta(r)\theta(p-r)-M^2Q\gamma\theta(p)-M^2Q\delta(p)}{(p+1)(p+2)} \tag{18}$$

with the boundary conditions,

$$\theta(0)=1,\quad \theta(1)=a$$

we arrived at

$$\theta(2)=\frac{-M^2Q}{2}+\frac{S_h}{2}-\frac{M^2Q\gamma_2}{2}+\frac{M^2}{2}-\frac{M^2Q\gamma}{2}$$

$$\theta(3)=\frac{aS_h}{3}-\frac{aM^2Q\gamma_2}{3}+\frac{M^2a}{6}-\frac{aM^2Q\gamma}{6}$$

$$\theta(4)=\frac{-S_hM^2Q\gamma}{8}-\frac{S_hM^2Q}{12}+\frac{S_h^2}{12}+\frac{S_hM^2}{8}$$
$$+\frac{M^4Q^2\gamma_1\gamma_2}{8}+\frac{M^4Q^2\gamma_2}{12}+\frac{M^4Q^2\gamma_2^2}{12}-\frac{M^4Q\gamma_2}{8}$$
$$-\frac{M^4Q\gamma}{12}+\frac{aM^4Q^2\gamma_2^2}{12}-\frac{M^4Q}{24}+\frac{M^4}{24}+\frac{M^4Q^2\gamma}{24}+\frac{M^4Q^2\gamma^2}{24}$$

$$\theta(5)=\frac{S_h^2aM^2}{12}-\frac{S_haM^2Q}{20}-\frac{S_h^2a}{12}-\frac{S_haM^2Q\gamma}{12}+\frac{aM^4Q^2\gamma_2}{20}-\frac{M^4Q^2\gamma_2^2a}{12}$$
$$+\frac{M^4Q^2\gamma_2^2aM^2}{12}+\frac{aM^4Q^2\gamma_1\gamma_2}{12}+\frac{aM^4}{120}-\frac{aM^4Q\gamma}{60}+\frac{M^4Q^2a\gamma^2}{120} \tag{19}$$

From the definition of DTM, we have,

$$\theta(X)=1+aX+\left(\frac{S_h}{2}-\frac{M^2Q}{2}-\frac{M^2Q\gamma_2}{2}+\frac{M^2}{2}-\frac{M^2Q\gamma}{2}\right)X^2+\left(\frac{aS_h}{3}-\frac{aM^2Q\gamma_2}{3}+\frac{M^2a}{6}-\frac{aM^2Q\gamma}{6}\right)X^3$$
$$+\left(\begin{array}{l}\frac{-S_hM^2Q\gamma}{8}-\frac{S_hM^2Q}{12}+\frac{S_h^2}{12}+\frac{S_hM^2}{8}+\frac{M^4Q^2\gamma_1\gamma_2}{8}+\frac{M^4Q^2\gamma_2}{12}+\frac{M^4Q^2\gamma_2^2}{12}\\ -\frac{M^4Q\gamma_2}{8}-\frac{M^4Q\gamma}{12}+\frac{aM^4Q^2\gamma_2^2}{12}-\frac{M^4Q}{24}+\frac{M^4}{24}+\frac{M^4Q^2\gamma}{24}+\frac{M^4Q^2\gamma^2}{24}\end{array}\right)X^4$$
$$+\left(\begin{array}{l}\frac{S_h^2aM^2}{12}-\frac{S_haM^2Q}{20}-\frac{S_h^2a}{12}-\frac{S_haM^2Q\gamma}{12}+\frac{aM^4Q^2\gamma_2}{20}-\frac{M^4Q^2\gamma_2^2a}{12}\\ +\frac{M^4Q^2\gamma_2^2aM^2}{12}+\frac{aM^4Q^2\gamma_1\gamma_2}{12}+\frac{aM^4}{120}-\frac{aM^4Q\gamma}{60}+\frac{M^4Q^2a\gamma^2}{120}\end{array}\right)X^5+\ldots. \tag{20}$$

For the solid fin

For the linear temperature-dependent internal heat generation is given as

$$\frac{d^2\theta}{dX^2}-M^2\theta+M^2Q\gamma\theta+M^2Q=0 \tag{21}$$

The recursive relation of the governing equation is given as

$$(p+1)(p+2)\theta(p+2)-M^2\theta(p)+M^2Q\gamma\theta(p)+M^2Q\delta(p)=0 \tag{22}$$

then

$$\theta(p+2)=\frac{M^2\theta(p)-M^2Q\gamma\theta(p)-M^2Q\delta(p)}{(p+1)(p+2)}$$

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With the boundary conditions, we arrived at

$$\theta(0)=1, \quad \theta(1)=a,$$

$$\theta(2)=\frac{-M^2Q}{2}+\frac{M^2}{2}-\frac{M^2Q\gamma}{2}$$

$$\theta(3)=\frac{M^2a}{6}-\frac{aM^2Q\gamma}{6} \tag{23}$$

$$\theta(4)=-\frac{M^4Q\gamma}{12}-\frac{M^4Q}{24}+\frac{M^4}{24}+\frac{M^4Q^2\gamma}{24}+\frac{M^4Q^2\gamma^2}{24}$$

$$\theta(5)=\frac{aM^4}{120}-\frac{aM^4Q\gamma}{60}+\frac{M^4Q^2a\gamma^2}{120}$$

Therefore,

$$\theta(X)=1+aX+\left(\frac{M^2}{2}-\frac{M^2Q}{2}-\frac{M^2Q\gamma}{2}\right)X^2+\left(\frac{M^2a}{6}-\frac{aM^2Q\gamma}{6}\right)X^2 +\left(\frac{M^4}{24}-\frac{M^4Q\gamma}{12}-\frac{M^4Q}{24}+\frac{M^4Q^2\gamma}{24}+\frac{M^4Q^2\gamma^2}{24}\right)X^4 +\left(\frac{aM^4}{120}-\frac{aM^4Q\gamma}{60}+\frac{M^4Q^2a\gamma^2}{120}\right)X^5+.... \tag{24}$$

For solid fin with nonlinear temperature-dependent internal heat generation is given as

$$\frac{d^2\theta}{dX^2}-M^2\theta+M^2Q\gamma_1\theta+M^2Q\gamma_2\theta^2+M^2Q=0 \tag{25}$$

And the recursive relation of the governing equation is given as

$$(p+1)(p+2)\theta(p+2)-M^2\theta(p)+M^2Q\gamma_2\sum_{r=0}^{p}\theta(r)\theta(p-r)+M^2Q\gamma\theta(p)+M^2Q\delta(p)=0 \tag{26}$$

From which we arrived at

$$\theta(p+2)=\frac{M^2\theta(p)-M^2Q\gamma_2\sum_{r=0}^{p}\theta(r)\theta(p-r)-M^2Q\gamma\theta(p)-M^2Q\delta(p)}{(p+1)(p+2)} \tag{27}$$

With the boundary conditions, we arrived at

$$\theta(0)=1, \quad \theta(1)=a, \quad \theta(2)=\frac{-M^2Q}{2}-\frac{M^2Q\gamma_2}{2}+\frac{M^2}{2}-\frac{M^2Q\gamma_1}{2}$$

$$\theta(3)=-\frac{aM^2Q\gamma_2}{3}+\frac{M^2a}{6}-\frac{aM^2Q\gamma_1}{6},$$

$$\theta(4)=\frac{M^3Q^2\gamma_1\gamma_2}{8}+\frac{\gamma_2M^4Q^2}{12}+\frac{M^4Q^2\gamma_2^2}{12}+\frac{M^4Q\gamma_2}{8}-\frac{M^4Q\gamma_1}{12} +\frac{aM^4Q^2\gamma_2^2}{12}-\frac{M^4Q}{24}+\frac{M^4}{24}+\frac{M^4Q^2\gamma_1}{24}+\frac{M^4Q^2\gamma^2}{24} \tag{28}$$

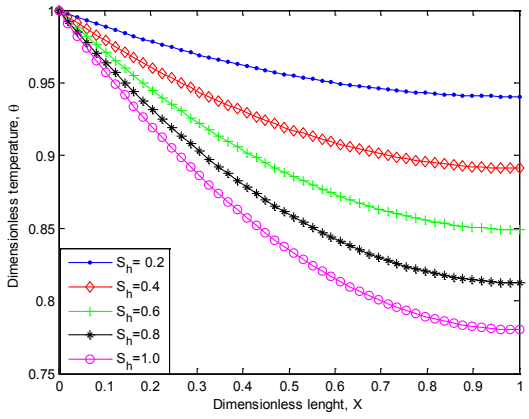
$$\theta(5)=\frac{aM^4Q^2\gamma_2}{20}-\frac{M^4Q^2\gamma_2^2a}{12}+\frac{M^4Q^2\gamma_2^2M^2}{12}+\frac{M^4Q^2\gamma_1\gamma_2}{12} +\frac{aM^4}{120}-\frac{aM^4Q\gamma_1}{60}+\frac{M^4Q^2a\gamma_1^2}{120}$$

Therefore,

$$\theta(X)=1+aX+\left(\frac{-M^2Q}{2}-\frac{M^2Q\gamma_2}{2}+\frac{M^2}{2}-\frac{M^2Q\gamma_1}{2}\right)X^2+\left(-\frac{aM^2Q\gamma_2}{3}+\frac{M^2a}{6}-\frac{aM^2Q\gamma_1}{6}\right)X^3 +\left(\frac{M^3Q^2\gamma_1\gamma_2}{8}+\frac{\gamma_2M^4Q^2}{12}+\frac{M^4Q^2\gamma_2^2}{12}+\frac{M^4Q\gamma_2}{8}-\frac{M^4Q\gamma_1}{12} +\frac{aM^4Q^2\gamma_2^2}{12}-\frac{M^4Q}{24}+\frac{M^4}{24}+\frac{M^4Q^2\gamma_1}{24}+\frac{M^4Q^2\gamma^2}{24}\right)X^4 +\left(\frac{aM^4Q^2\gamma_2}{20}-\frac{M^4Q^2\gamma_2^2a}{12}+\frac{M^4Q^2\gamma_2^2M^2}{12}+\frac{M^4Q^2\gamma_1\gamma_2}{12} +\frac{aM^4}{120}-\frac{aM^4Q\gamma_1}{60}+\frac{M^4Q^2a\gamma_1^2}{120}\right)X^5+.... \tag{29}$$

## 4. Results and Discussion

Using the developed models, the graphical representations of the results are presented in this section. Figures 2a-d present the impacts of porosity on thermal behaviour of the porous fin. As expected, the figures illustrate heat transfer enhancement by the porous parameter.




**(a)**



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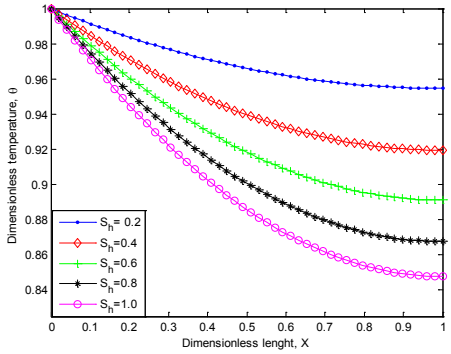
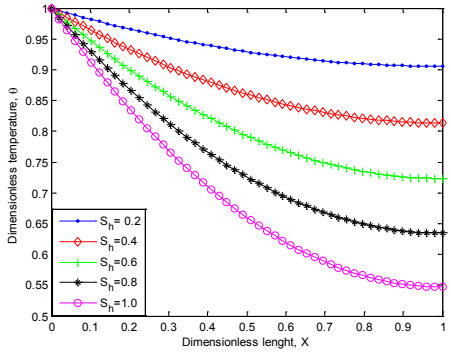
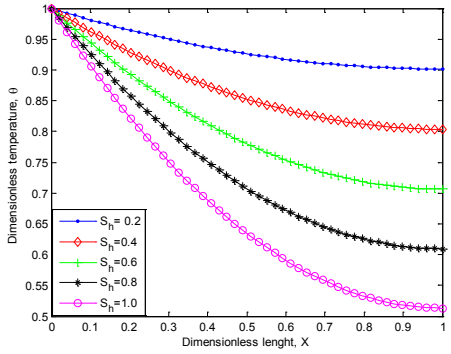



**(b)**



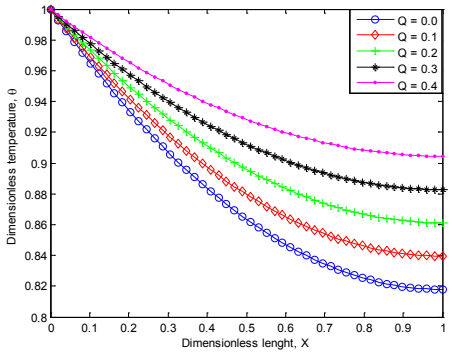

**(c)**



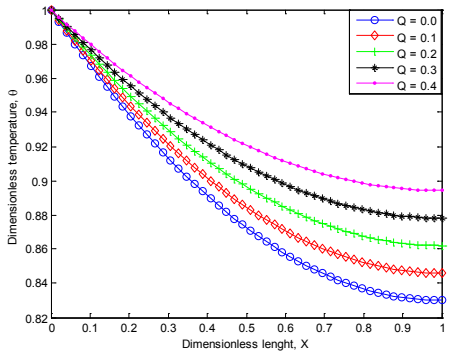

**(d)**

**Figure 2.** Impacts of porosity on the fin temperature when (a) M=0.5, Q=0.2, γ=0.4 (b) M=1.0, Q=0.2, γ=0.4 (c) M=5.0; Q=0.4, γ=0.2 (d) ) M=10, Q=0.2, γ=0.4

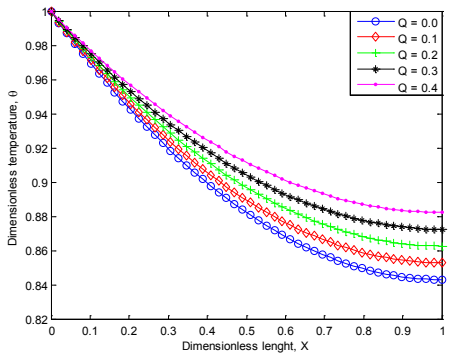
The influences of the internal heat parameter on the thermal response of the porous fin is shown in Figure 3a-d and Figure 4a-b. It can be seen that the internal heat parameter decreases the thermal performance of the fin. Also, it is shown that when the internal heat parameter increases to some certain values, the purpose of heat dissipation by the porous was greatly defeated as the fin stores heat rather than dissipating it.



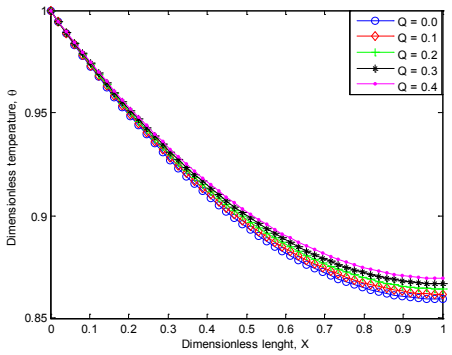

**(a)**




**(b)**




**(c)**




**(d)**

**Figure 3.** Influences of internal heat parameter on the fin temperature distribution when (a) M=0.1, $S_h$=0.5, γ=0.2 (b) M=0.5, $S_h$=0.5, γ=0.2, (c) M=0.75, $S_h$=5.0, γ=0.2 (d) M=1.0, $S_h$=0.5, γ=0.2

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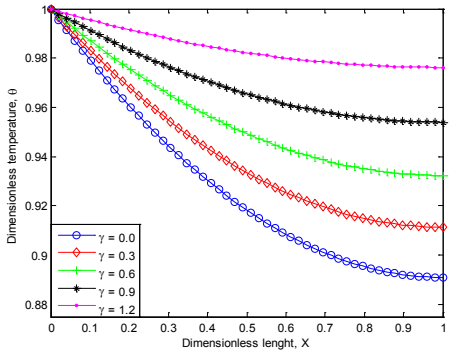
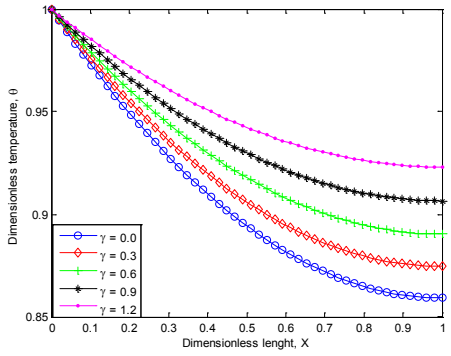
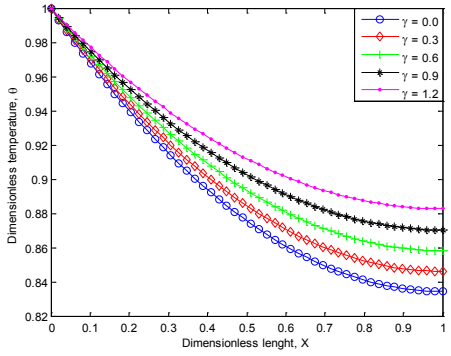


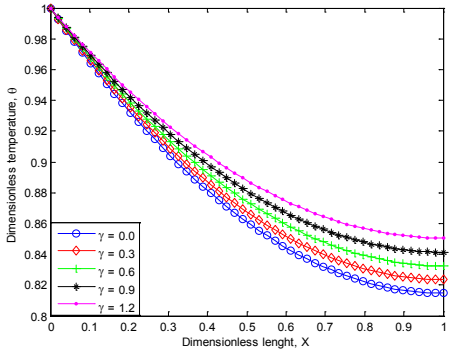

(a)




(b)

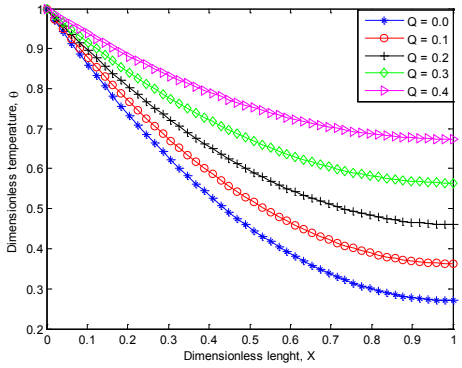



(c)

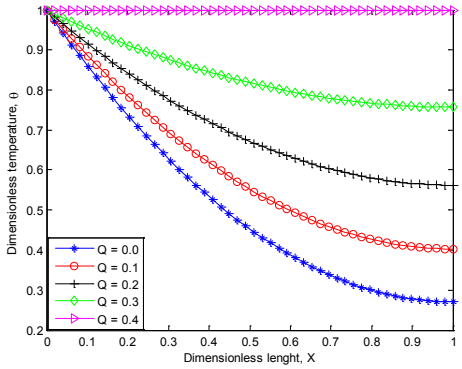



(d)

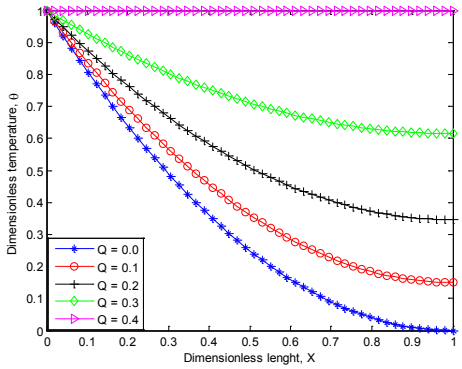
**Figure 4.** Effects of the internal heat parameter on fin temperature when (a) M=0.5, Q=0.4, $S_h$=0.5, (b) M=1.0, Q=0.4, $S_h$=0.5(c) M=1.5, Q=0.4, $S_h$=0.5 (d) M=2.0, Q=0.4, $S_h$=0.5



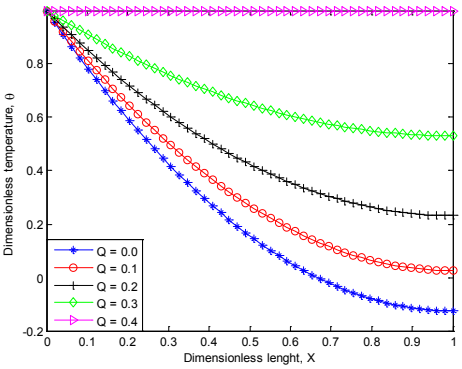

(a)




(b)



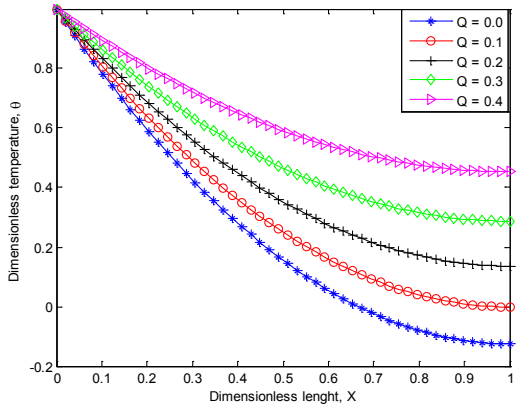

(c)



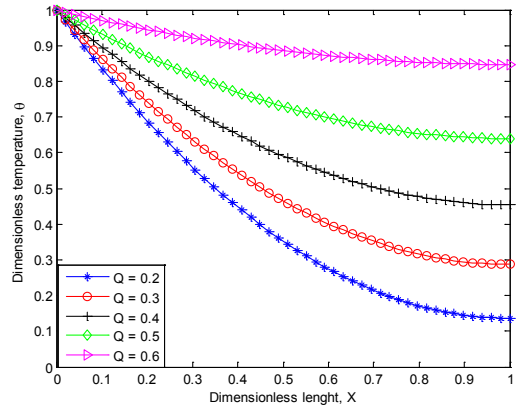

(d)



DOI: https://doi.org/10.30564/ssid.v2i1.1888




**(e)**




**(f)**

**Figure 5.** Impacts of internal heat values on when (a) S=0, M=2, G=0.5 (b) S=0, M=2, G=1.5 (c) S=0, M=3.35, G=1.5 (d) S=0, M=5.0, G=1.5 (e) S=0, M=5, G=0.5 (f) S=0, M=5.0, G=0.5

Also, further display of the results of the impacts of internal heat parameter on the thermal response of the fin is illustrated in Figure 5a-f. In our previous study [27], it was established that the limiting value of the porous parameter, $S_h$ for thermal stability for fin with constant thermal properties and without internal heat parameter is approximately $4\sqrt{34}$. However, it was established in the present study that this limiting value of porosity parameter increases internal heat parameter, Q increases. This shows that although the internal heat parameter can help assist higher range and value of thermal stability of the fin, it also produces negative effect which greatly defeats the ultimate purpose of the fin where the fin stores heat rather than dissipating it.

## 5. Conclusion

In this work, impacts of internal heat generation on the heat transfer dissipation capacity of porous and solid fin is studied using differential transformation method. The parametric studies reveal that porosity enhances the fin heat dissipating capacity but the internal heat parameter decreases the thermal performance of the fin. Also, it was established that when the internal heat parameter increases to some certain values, some negative effects are recorded where the fin stores heat rather than dissipating it. This scenario defeats the prime purpose of the cooling fin. A further parametric study revealed that the limiting value of porosity parameter for thermal stability for the fin increases as internal heat parameter increases. This shows that although the internal heat parameter can help assist higher range and value of thermal stability of the fin, it produces negative effect which greatly defeats the ultimate purposes of the fin of heat dissipation and heat transfer enhancement. Therefore, it is highly recommended that the operational parameters of the extended surface must be properly selected for required purpose.

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# Author Guidelines

This document provides some guidelines to authors for submission in order to work towards a seamless submission process. While complete adherence to the following guidelines is not enforced, authors should note that following through with the guidelines will be helpful in expediting the copyediting and proofreading processes, and allow for improved readability during the review process.

## Ⅰ. Format

- Program: Microsoft Word (preferred)
- Font: Times New Roman
- Size: 12
- Style: Normal
- Paragraph: Justified
- Required Documents

## Ⅱ. Cover Letter

All articles should include a cover letter as a separate document.

The cover letter should include:

- Names and affiliation of author(s)

The corresponding author should be identified.

Eg. Department, University, Province/City/State, Postal Code, Country

- A brief description of the novelty and importance of the findings detailed in the paper

Declaration

v Conflict of Interest

Examples of conflicts of interest include (but are not limited to):

- Research grants
- Honoria
- Employment or consultation
- Project sponsors
- Author’s position on advisory boards or board of directors/management relationships
- Multiple affiliation
- Other financial relationships/support
- Informed Consent

This section confirms that written consent was obtained from all participants prior to the study.

- Ethical Approval

Eg. The paper received the ethical approval of XXX Ethics Committee.

- Trial Registration

Eg. Name of Trial Registry: Trial Registration Number

- Contributorship

The role(s) that each author undertook should be reflected in this section. This section affirms that each credited author has had a significant contribution to the article.

1. Main Manuscript
2. Reference List
3. Supplementary Data/Information

Supplementary figures, small tables, text etc.

As supplementary data/information is not copyedited/proofread, kindly ensure that the section is free from errors, and is presented clearly.

## Ⅲ. Abstract

A general introduction to the research topic of the paper should be provided, along with a brief summary of its main results and implications. Kindly ensure the abstract is self-contained and remains readable to a wider audience. The abstract should also be kept to a maximum of 200 words.

Authors should also include 5-8 keywords after the abstract, separated by a semi-colon, avoiding the words already used in the title of the article.

Abstract and keywords should be reflected as font size 14.

## Ⅳ. Title

The title should not exceed 50 words. Authors are encouraged to keep their titles succinct and relevant.

Titles should be reflected as font size 26, and in bold type.

## Ⅳ. Section Headings

Section headings, sub-headings, and sub-subheadings should be differentiated by font size.

Section Headings: Font size 22, bold type

Sub-Headings: Font size 16, bold type

Sub-Subheadings: Font size 14, bold type

Main Manuscript Outline

## Ⅴ. Introduction

The introduction should highlight the significance of the research conducted, in particular, in relation to current state of research in the field. A clear research objective should be conveyed within a single sentence.

## Ⅵ. Methodology/Methods

In this section, the methods used to obtain the results in the paper should be clearly elucidated. This allows readers to be able to replicate the study in the future. Authors should ensure that any references made to other research or experiments should be clearly cited.

## Ⅶ. Results

In this section, the results of experiments conducted should be detailed. The results should not be discussed at length in

this section. Alternatively, Results and Discussion can also be combined to a single section.

## Ⅷ. Discussion

In this section, the results of the experiments conducted can be discussed in detail. Authors should discuss the direct and indirect implications of their findings, and also discuss if the results obtain reflect the current state of research in the field. Applications for the research should be discussed in this section. Suggestions for future research can also be discussed in this section.

## Ⅸ. Conclusion

This section offers closure for the paper. An effective conclusion will need to sum up the principal findings of the papers, and its implications for further research.

## Ⅹ. References

References should be included as a separate page from the main manuscript. For parts of the manuscript that have referenced a particular source, a superscript (ie. [x]) should be included next to the referenced text.

[x] refers to the allocated number of the source under the Reference List (eg. [1], [2], [3])

In the References section, the corresponding source should be referenced as:

[x] Author(s). Article Title [Publication Type]. Journal Name, Vol. No., Issue No.: Page numbers. (DOI number)

## Ⅺ. Glossary of Publication Type

J = Journal/Magazine

M = Monograph/Book

C = (Article) Collection

D = Dissertation/Thesis

P = Patent

S = Standards

N = Newspapers

R = Reports

Kindly note that the order of appearance of the referenced source should follow its order of appearance in the main manuscript.

Graphs, Figures, Tables, and Equations

Graphs, figures and tables should be labelled closely below it and aligned to the center. Each data presentation type should be labelled as Graph, Figure, or Table, and its sequence should be in running order, separate from each other.

Equations should be aligned to the left, and numbered with in running order with its number in parenthesis (aligned right).

## Ⅻ. Others

Conflicts of interest, acknowledgements, and publication ethics should also be declared in the final version of the manuscript. Instructions have been provided as its counterpart under Cover Letter.

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