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ARTICLE

Development of Recovery and Redundancy Model for Real Time Wireless Networks

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ABSTRACT

The growth in wireless technologies applications makes the necessity of providing a reliable communication over wireless networks become obvious. Guaranteeing real time communication in wireless medium poses a significant challenge due to its poor delivery reliability. In this study, a recovery and redundancy model based on sequential time division multiple access (S-TDMA) for wireless communication is developed. The media access control (MAC) layer of the S-TDMA determines which station should transmit at a given time slot based on channel state of the station. Simulations of the system models were carried out using MATLAB SIMULINK software. SIMULINK blocks from the signal processing and communication block sets were used to model the communication system. The S-TDMA performance is evaluated with total link reliability, system throughput, average probability of correct delivery before deadline and system latency. The evaluation results displayed in graphs when compared with instant retry and drop of frame were found to be reliable in recovering loss packets.

1. Introduction

Ascertaining an unhindered real-time delivery in wireless communication medium is challenging. It has poor delivery reliability compared to wired networks [1]. Real-time applications in wireless broadcast have stringent and short transfer deadline thereby making packet loss recovery more difficult [2]. Real-time communication is the application that demands a certain quality of service (QoS) to the communication network like maximum delay, maximum loss rate upon its connection to guarantee the requested service quality [3]. The real-time measurement of a network is its ability to carry information for given time limit. In other words, real-time information has to be received by the recipient before a certain deadline [4]. Some important features of real time applications as discussed

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in Al-Kuwaiti [5] are timeliness, peak load design, predictability, fault tolerance and maintainability.

Time division multiple access (TDMA) approach has been proving useful in resolving the issue of medium contention and frame collisions but frame reception remains unpredictable as a result of its dynamic and shared nature of the medium [1]. Real-time MAC protocol uses TDMA to provide stations with a mechanism to reserve a transmission slot in a TDMA cycle of network. The calculation of the required transmission time needs to take into account the number of retransmissions that may be required to achieve a given reliability. The wireless shared nature allows transmissions to be intercepted by noise in the environment. Such interference is commonly addressed by using protocols like TDMA.

In wireless networks, media access control (MAC) protocols like carrier-senses multiple access with collision avoidance (CSMA/CA), multiple access with collision avoidance (MACA) are liable to contention and collisions because of different attempting stations to access the medium the same time [6]. Hence, TDMA channel access approach provides collision and contention-free medium access. Transmission errors occur simply due to background noise, transient propagation effects and so on. Burst errors characterized by a distribution of occurrence and distribution of length of a burst are detected as frame losses [1,7]. Wireless Frame losses are unavoidable; therefore, its recovery effectiveness is important. As soon as burst errors condition lead to the loss of frame(s), the station transmitting must retransmit the affected frame(s) in a way to minimize its possible re-occurrence and still reduce its impact on frames to other destinations. The instant retry approaches, probabilistic backoff, fixed-delay backoff, exponential backoff, frames re-queuing, link quality estimate, congestion awareness, packet rejection estimation and drop of frame approaches have all been used [8,9].

In designing a proficient MAC protocol for wireless networks, the characteristics like energy efficiency, scalability, adaptively, latency, channel utilization, throughput and fairness must be considered [10,11]. Collision occurs in wireless networks once two nodes transfer data at a time over transmission medium. Such problem can be addressed by employing MAC protocol to mediate access to the shared medium to avoid data collision and maintain a fairly efficient sharing of the bandwidth resources. The retransmissions approach may be alright for shared wired media but not over wireless media. The signals to two destinations over a wireless medium will broadcast over diverse paths and meet with different environmental factors. This may results to failed transmission to station A but successful for station B at the same time. Due to these observations, a retransmission protocol that takes into account the characteristics of wireless medium and attempts to re-order the transmission queue following failed transmissions is proposed. This work was designed and implemented using Simulink simulator in Matlab.

The rest of this paper is organized thus: Section 2 and 3 reviews the related literature and describes the design of the S-TDMA system model respectively. Section 4 describes the analysis of performance metric used while section 5 addresses simulation of the system model. The conclusion drawn from the study forms the final section.

2. Related Works

Fault recovery and redundancy in real-time wireless TDMA was studied by Gleeson and Weber [1]. The paper addresses the problem of message delivery reliability in real-time, wireless communication systems, as well as, probabilistic admissions control protocol provision. Two hybrid approaches were used to make the satisfaction of real-time guarantees in on-time packet delivery. These are admissions control and an exponential backoff. Admission control ensures that transmission time is reserved so as to make retransmissions possible while an exponential backoff process rescheduled failed transmissions on a station-by-station basis. The work ensures that the real-time was guaranteed while allowing a limited loss of frames. Ali et al. [11] proposed distortion-based slice level prioritization for real-time video over QoS-enabled wireless networks. The work showed that given a higher-priority to some classified packets in accessing the wireless media, a considerable quality was achieved when prioritization is not used.

A self-regulated redundancy control scheme for high-bit-rate video transmission using packet-level forward-error-correction (FEC) codes over error-prone wireless networks was presented by Shih et al. [12]. Packet-level FEC was used for the self-regulated redundancy scheme to support the high-speed video transmission in wireless networks. The proposed scheme protects video streams from wireless losses as well as controls the redundancy degree to reduce the adverse effect of FEC efficiency. Bassey et al. [13] examined mitigating effect of packet losses on real-time video streaming using peak signal-to-noise ratio (PSNR) as video quality assessment metric. Real-time live video content streaming over the Internet is complicated as a result of bandwidth, jitter, packet losses and fair sharing of network resources among users. The work uses PSNR as video quality assessment metric to moderate packet losses on real-time video streaming. The video frame rates were compressed and the results showed the higher the PSNR, the lower the loss rate, and the better the video quality.

Wang et al. [14] studied hybrid recovery strategy based on random terrain (HRSRT) in wireless sensor networks. It was stated that getting fruitful data collection and aggregation is main goal for a broad spectrum of wireless sensor networks applications but connectivity loss in a network may bring failure in data aggregation. The work uses HRSRT that takes both realistic terrain influences and quantitative limitations of relay devices into consideration. The simulation results showed that HRSRT performs better in terms of overall energy cost. Modular redundancy for cloud based IP multimedia subsystem (IMS) robustness was explored by Raza et al. [15]. IMS is an emerging communication framework that provides a wide range of multimedia services such as video over LTE, interactive gaming in active LTE network. Due to the emerging applications support, network operators are embracing cloud-based IMS and are deploying it to meet the need of increasing multimedia traffic demand. This paper revealed that cloud-based IMS cannot provide session-level resilience under faults. The origin of the problem stems from the weak failure recovery mechanisms. In other to solve this, fault-tolerance design to IMS control-plane processes was proposed. The outcomes showed that session-level resilience can be achieved by carrying out fail-over procedure within tens of milliseconds under different combinations of IMS control-plane operations failures.

Hybrid cross layer fault resilient energy efficient data transmission for underwater acoustic sensor networks was done by Vidyalakshmi et al. [16]. The solution proposed in this work ensures high packet delivery ratio with low energy consumption. According to the experimental analysis, the proposed work out-performs the existing works when considering packet delivery ratio, life time as well as network overhead. Arefi and Khabbazian [2] examined packet loss recovery in broadcast for real-Time applications in dense wireless networks. This work introduces random instantly decodable network coding (RIDNC) which is a random encoding approach to instantly decodable network coding (IDNC) which was referred to as random IDNC encoder (RACE). It was observed that RACE compared with the CrowdWiFi encoder using simulations, recovers more lost packets.

He and Zhou [17] presented real-time data recovery in wireless sensor networks (WSN) using spatiotemporal correlation based on sparse representation. Historical data, joint low-rank constraint and temporal stability were used as data for spatiotemporal correlation. The simulation results showed the proposed method beats the compressed sensing (CS) method with sparse sensing matrix, joint CS and matrix completion method. Lucas-Estañ et al. [18] studied a work on redundancy and diversity in wireless networks. The work supported mobile industrial applications in Industry 4.0 otherwise known as Factories of the Future (FoF). Evaluation through simulation reveals how the capacity of diversity and redundancy improve the reliability and latency of wireless networks for mobile industrial applications. Kim et al. [19] presented a survey on real-time communications in wireless sensor networks. It presented the up-to-date research approaches and discussed some features that are important to real-time communications networks in wireless sensor. It was partitioned into hard, soft, and firm real-time model. It was observed that MAC scheduling and routing were common to all the categories. The work concluded with suggestions to potential directions for future research.

3. Design of the S-TDMA System Model

In this study, a recovery and redundancy model for wireless communication using sequential TDMA (S-TDMA) is designed. The S-TDMA MAC-layer determines which station should be allowed to transmit at an allotted time slot based on the channel state of the station. The S-TDMA time slot scheme for 6 stations is shown in Figure 1. Each station is given a time slot to transmit. A slot is a super frame which contains the beacon frame (BC), data frames of varying sizes and reserved frames for retransmission in case of failed detection. The beacon is used to distinctively identify the super frame and its transmitter. Each time slot in the S-TDMA cycle is of fixed size and a station can use any of the available slots to transmit. The flowchart for the designed S-TDMA model is presented in Figure 2.

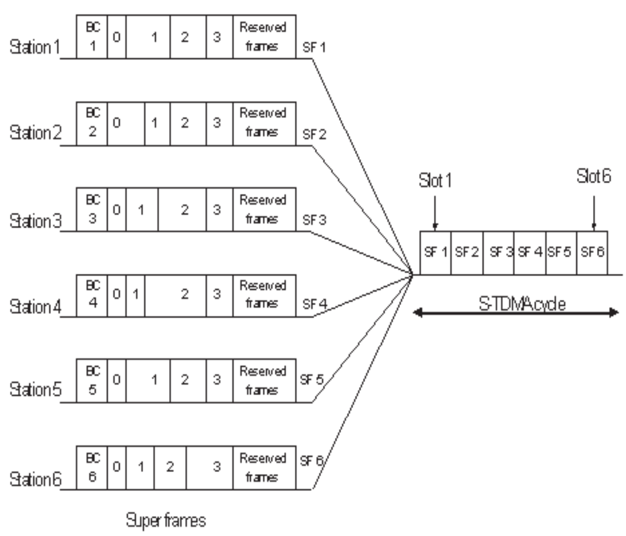

Figure 1. S-TDMA Time Slot Scheme in MAC Layer

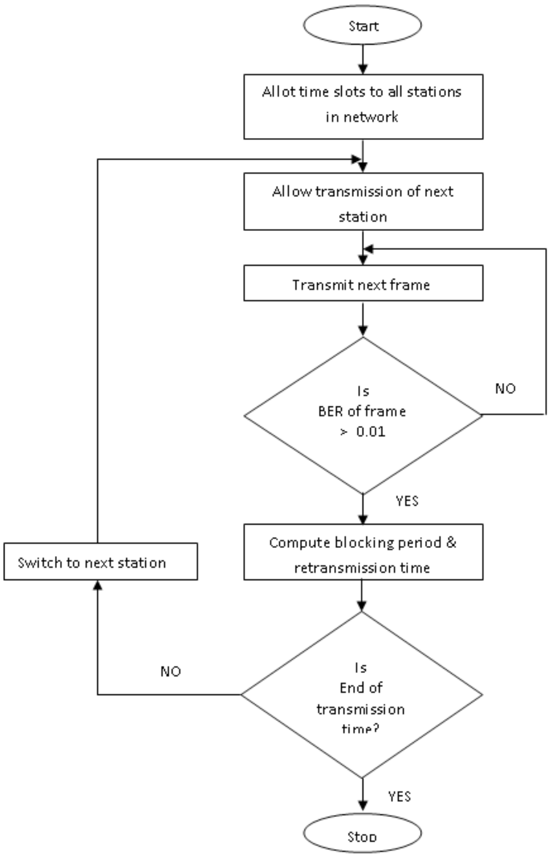

Figure 2. Flowchart of the designed S-TDMA

4. Performance Metric analysis

The performance of the designed S-TDMA model was based on these performance metrics: total link reliability (TLR), throughput (τ), average probability of correct delivery before deadline ($\overline{P}_d$) and system latency (L). These metrics are described in this section and they are used to measure the degree of quality-of-service (QoS) of the system.

Total Link Reliability (TLR)

Link reliability is a measure of the success of data transmissions in a wireless communication system. A reliable wireless communication link ensures the information data transmitted from the source is received correctly at the sink without any data loss.

Assuming a station n transmitted some frames, then, the total sum of frames successfully transferred is given in Equation (1):

$$F_{succ}(n) = \sum_i n_i \tag{1}$$

where $F_{succ}(n)$ is the total number of frames successfully transmitted by station, thus, the probability that some frames are lost during transmission is obtained in Equation (2):

$$p_{loss}(n) = \frac{\{F_{rq} - F_{succ}(n)\}}{F_{rq}} \tag{2}$$

where $p_{loss}(n)$ is the frame loss probability and F_{rq} stands for the required number of frames to be transmitted successfully.

The TLR of the wireless network is the sum of the link reliabilities of all the stations utilizing the network and hence, the total link reliability for the network is expressed using Equation (3):

$$TLR = \frac{1}{N}\sum_{n=1}^{N} LR(n) \times 100\% \tag{3}$$

where N is the total stations, therefore, link reliability for the n^{th} station is obtained in Equation (4) [20]:

$$LR(n) = 1 - p_{loss}(n) \tag{4}$$

where $p_{loss}(n)$ had been defined earlier in Equation (2).

System throughput (τ)

System throughput is defined as the rate of transmission of data packets by the system. It depends on the number of data successfully transmitted within a given period of time, and it is measured in megabits per second (Mbps). The system throughput is expressed in Equation (5):

$$\tau = \frac{\text{total packets successfully tramsmitted}}{\text{Maximun transmission time}} \tag{5}$$

Average probability of correct delivery before deadline ($\overline{p}_d$)

A recovery MAC protocol would request retransmission of the frames that are not correctly received by the transmitting station,, thus, a specific time is assigned for this transmission, however, the station may not be able to retransmit successfully till this time elapses.

The probability of correct delivery of frames before deadline by station n can be expressed using Equation (6):

$$p_d(n) = \frac{1}{R}\sum_i \left[1 - p_f(i)\right] \tag{6}$$

where the probability of a frame of station n failing on the i^{th} attempt is given in Equation (7):

$$p_f(i) = P_e(i)^{(R-1)+1} \tag{7}$$

But $p_e(i)$ is error probability or BER and R is number of retransmissions.

Therefore, when considering all the stations in the network, the average probability of correct delivery before deadline will be expressed Equation (8).

$$\overline{p}_d = \frac{1}{N}\sum_{n=1}^{N} p_d(n) \tag{8}$$

where N is the summation of stations in the network [20].

Meanwhile, error probability (p_e) or BER is calculated in the simulation using Equation (9):

$$BER = \frac{\text{number of error or corrupted bits}}{\text{total number of hits transmitted}} \quad (9)$$

System Latency (L)

System latency is the time delay experienced by the system in successfully transmitting a given volume of data, therefore any system that gives moderately low or negligible latency is assumed to be fast. It is commonly expressed in milliseconds and can be given using Equation (10):

$$L = \frac{\text{total time taken}}{\text{total packets successfully transmitted}} \quad (10)$$

5. Simulation of the System Model

The models simulations were carried out using MATLAB/SIMULINK. SIMULINK blocks from the signal processing and communication blocksets were used to model the communication system. Table 1 shows the parameter used for the models simulation. MATLAB was utilized in this study because of its ease of use and graphical presentation of results.

Table 1. Simulation Parameters for the three Models

Parameters	Model		
	Instant retry	Drop of frame	S-TDMA
Maximum Number of Stations	6	6	6
Maximum Number of Packets	100	100	100
Maximum number of retransmission	NA	3	NA
Frame length	50	50	50
Blocking period	0 ms	0 ms	200 ms
Time slot per station	180 ms	180 ms	180 ms
Modulation type	MPSK	MPSK	MPSK
Modulation order	4	4	4

System Total Link Reliability

The developed S-TDMA model is compared with two of the existing models namely drop-of-frame and instant retry. Figure 3 shows the performances of three models in relations to total link reliability. Link reliability is a measure of the success of data transmissions in a wireless communication system. The total link reliability results of the drop-of-frame model for stations of 2, 3, 4, 5 and 6 networks are 93.00%, 92.67%, 91.50%, 94.40%, 94.00% respectively. The results reveal that the total link reliability of the drop-of-frame model is dependent on how many of the stations are effective in the network and not necessarily the number of stations utilizing the channel.

For the instant retry model, the total link reliability for stations of 2, 3, 4, 5 and 6 are 84.00%, 85.33%, 97.00%, 92.80% and 96.00% respectively. These results for the instant retry model also reveal that though the reliability tends to increase with increasing number of stations, the total link reliability is dependent on how many of the stations are effective in the network and not necessarily the number of stations utilizing the channel. For the S-TDMA model, the total link reliability for stations of 2, 3, 4, 5 and 6 are 100%, 100%, 100%, 100% and 100%, respectively. This reveals that in the S-TDMA model, all the transferrable data were successfully transmitted during the transmission period unlike the other two models where some of the frames could not be transmitted before the transmission period elapsed. The developed S-TDMA model is able to achieve this because each Station consists of a backup transmitter in case the main transmitter fails to start transmission immediately the channel is open for the station by the MAC controller. This process helps to handle redundancy at each station in the communication network, thereby, eliminating downtime.

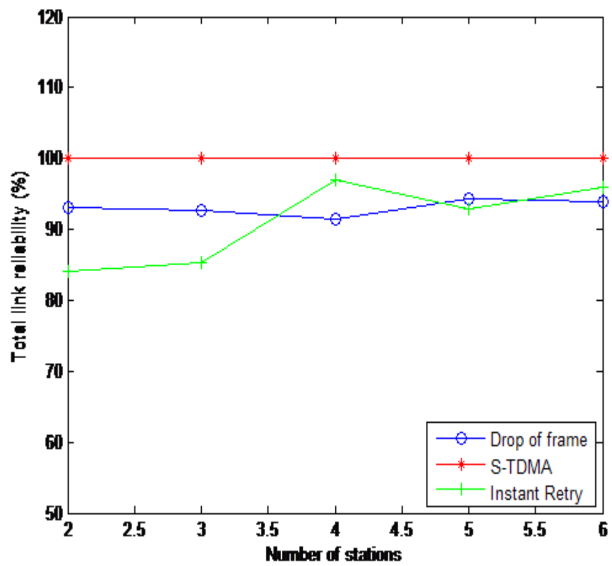

Figure 3. Total link reliability

System Throughput

System throughput is the rate of transmission of data packets by the system. The system throughput performances for the models are compared in Figure 4. The system throughputs in the drop-of-frame model for stations of 2, 3, 4, 5 and 6 are 3.1667 Mbps, 3.1556 Mbps, 3.1167 Mbps, 3.8800 Mbps and 3.7667 Mbps respectively. This shows that the system throughput in the drop-of-frame model is independent of the number of stations in the network. The system throughputs in the instant retry model for stations of 2, 3, 4, 5 and 6 are 2.8000 Mbps, 2.8444 Mbps, 3.2333 Mbps, 3.0933 Mbps and 3.2000 Mbps respectively. This also shows that the system throughput in the instant retry model is independent of the number of stations in the network. However, the drop-of-frame model gives relatively higher throughput than the instant retry model. This is because the drop-of-frame model drops any frame that would cause redundancy for the system to keep transmitting without delay but with a tradeoff of lost frames. The system throughputs in the S-TDMA model for stations of 2, 3, 4, 5 and 6 are 3.3333 Mbps, 3.3333 Mbps, 3.3333 Mbps, 3.3333 Mbps and 3.3333 Mbps respectively. These results also reveal that the system throughput in the S-TDMA model is not dependent stations number in the network. However, the S-TDMA gives relatively higher throughput than both the drop-of-frame and instant retry models. This is because the S-TDMA model allocates transmission and a retransmission period dynamically depending on the state of the networks, which helps to eliminate redundancy in the network and also ensures that all the frames are successfully transmitted.

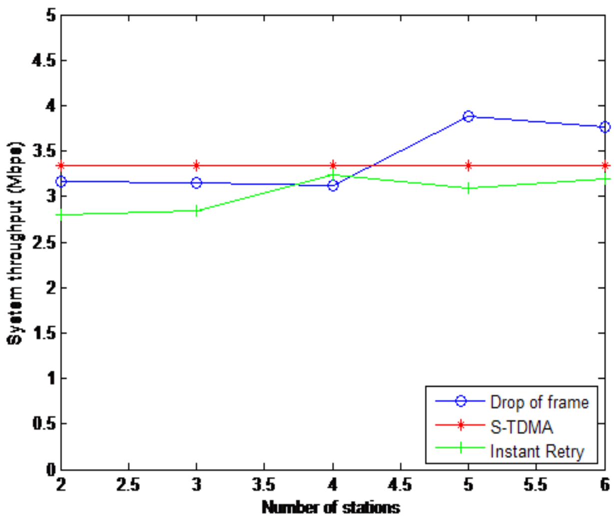

Figure 4. System throughput

Probability of Correct Delivery

This is the average probability of correct delivery of frames before deadline by any station. Figure 5 presents the performances of the models in terms of average probability of correct delivery before deadline. For stations of 2, 3, 4, 5 and 6, the drop-of-frame model gives 0.9500, 0.9467, 0.9350, 0.9640 and 0.9600 respectively. The instant retry model gives 0.9919, 0.9926, 0.9910, 0.9950 and 0.9955 for stations of 2, 3, 4, 5 and 6 respectively. The S-TDMA model gives 0.9949, 0.9936, 0.9905, 0.9894 and 0.9949 for stations of 2, 3, 4, 5 and 6 respectively. From the results, the Instant retry model gives relatively higher average probability of correct delivery when compared to the drop-of-frame model. This is because the drop-of-frame model drops redundant frames thereby losing then during transmission, while the instant retry model keeps trying to retransmit the redundant frames until they finally get to the receiving end; and this gives more success to the instant retry model in terms of frame delivery. However, the S-TDMA model gives relatively similar average probability of correct delivery performance when compared to the instant retry model. This is because the S-TDMA model also ensures that every frame gets to the receiving end.

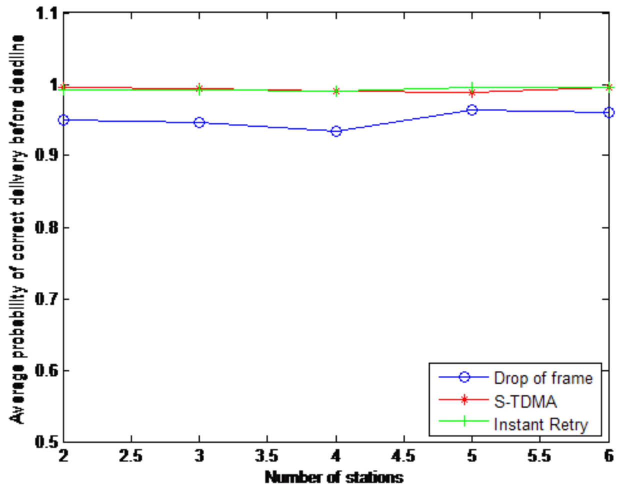

Figure 5. Average probability of correct delivery before deadline

System Latency

The performances of the models in terms of system latency were presented in Figure 6. System latency is the time delay experienced by the system in successfully transmitting a given volume of data. This is measured in milliseconds. For stations 2, 3, 4, 5 and 6, the drop-of-frame model gives 0.3158, 0.3169, 0.3209, 0.2577 and 0.2655, respectively. The instant retry model gives 0.3571, 0.3516, 0.3093, 0.3233 and 0.3125 for the stations of 2, 3, 4, 5 and 6 respectively. The S-TDMA model gives 0.3000, 0.3000, 0.3000, 0.3000 and 0.3000 for the stations of 2, 3, 4, 5 and 6 respectively. These results reveal that the system latency for the drop-of-frame model is relatively lower than that of the instant retry model. This is due to the fact that the instant retry model experiences more delay in trying to repeatedly retransmit a redundant frame, while the drop-of-frame eliminates the delay by dropping any redundant frame so as to allow the active ones to utilize the channel at any time period. The system latency for the S-TDMA is however shown to be constant for all the number of stations considered in the network and the latency is relatively higher than those of drop-of-frame for 5 stations and 6 stations. This implies that for the S-TDMA model, the system latency is independent of the number of stations in the network; however, the drop-of-frame reduces system latency with increasing number of stations when compared to both the S-TDMA and instant retry models.

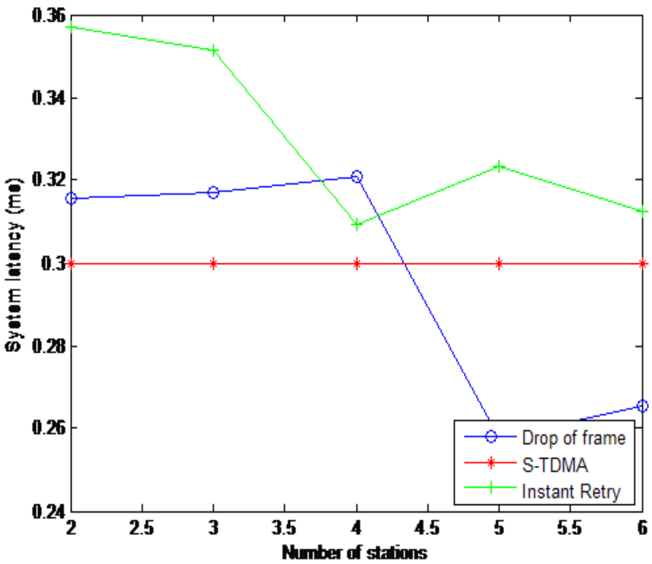

Figure 6. System latency

6. Conclusions

In this study, S-TDMA designed model is used as a recovery and redundancy model for real time wireless network. The model utilizes MAC protocol based on TDMA and the MAC layer of the S-TDMA to determine which station should be permitted to transmit at a given time slot based on the channel state of the station. The S-TDMA system model was simulated with MATLAB SIMULINK. The model is compared with two other existing models; drop of frame and instant retry. The metrics used to evaluate the performance of the designed S-TDMA are total link reliability, system throughput, average probability of correct delivery before deadline and system latency. The results of the metrics are displayed in graphs and tables. These metrics give the degree of Quality of Service (QoS) delivery of the system. The developed program is tested and found to be reliable in recovery of loss packets. Since the designed model has been able to provide an effective means of recovering loss frames, it is therefore recommended to be used by industries in order to combat the problem of message delivery reliability in wireless network since it performs better than other existing models.

Conflict of Interest

There is no conflict of interest.

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