Modeling Throughput Performance in 802.11 Wireless Local Area Network

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Abstract- This paper presents a mathematical framework for maximizing throughput in wireless local Area Networking (WLAN) Channels using Key System design parameter such as MATLAB. We study the trade-off between the throughput and choice of some design variables through extensive computer simulation. We observe from the simulation results that the design parameters are highly signal dependent and can dynamically be adapted to improve the overall system performance, principally in the area of data transmission and reception in WLAN Channels.

Indexed Terms- Modeling throughput performance, 802.11 wireless and local area network

I. INTRODUCTION

Previous years has witnessed rapid development of wireless communication and technologies. Rapid growth in the number of wireless devices such as smart phones, PCs, personal digital assistants and home entertainment systems, along with the rapid formation of advanced multimedia applications, such as Voice Over-IP (VoIP), Video Conferencing, IPTV, Telemedicine and Internet Gaming have resulted in revolutionary advance and deployment of the wireless technology. Noted for being the most desired networking technology of choice, IEEE 802.11 based Wireless Local Area Networks (WLANs), also known as Wi-Fi (Wireless Fidelity) (IEEE 2013), have experienced impressive commercial success owing to their low cost and easy deployment.

WLANs have connected an immensely expanding range of user-centric WiFi-equipped mobile devices over the last decade. With consumer services and applications that are persistently in need of a ubiquitous network access, WLANs are the preferred means of internet access for users and product developers worldwide.

However, the constant increase in demand for high bandwidth and Quality-of-Service (QoS) of high-definition multimedia applications in WLANs has made them extremely dense, posing great challenges on their design and deployment. Several technology forecasts predict that by 2020, the global mobile data traffic is expected to increase nearly eightfold. With 75% of the mobile data traffic being video, it is expected for the mobile data traffic to reach an average of 30.6 Exabyte per month, 53 percent higher than it was in 2015 (http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html. (2016). A 17 great portion of this increasing high volume traffic is generated and carried through WLANs.

The great strain of constant and continuous high-volume generation of multimedia traffic and in particular video will be a stern test for the 802.11-based WLANs. With the emergence of video streaming websites such as Netflix, Hulu, YouTube, and etc., video applications are recognized as significant drivers of current network traffic. As well as video, high volumes of traffic is generated as a result of online and instantaneous data synchronization and backups through mobile devices alongside the use of VoIP applications such as Skype and FaceTime. Since its first release in 1997, the IEEE 802.11 standard has gone through various stages of development. Nonetheless, the primary aim of this standard, simple and best effort local area communication has always been a priority.

However, almost all previous amendments to the standard were aimed at increasing the peak physical data rate through the exploitation of new modulation and coding schemes and recently through the use of Multiple-Input-Multiple-Output (MIMO) antenna mechanisms.

The IEEE 802.11 standard only deals with the two lowest layers of the Open System Interconnection (OSI) reference model: the Medium Access Control layer (MAC) (a sub-layer of the Data Link layer), and the Physical layer (PHY).

The MAC layer offers two types of contention free channel access service: 1) a service provided by the Distributed Coordination Function (DCF), and 2) a polling-based service provided by the Point Coordination Function (PCF). These services are available on top of the Physical layer. DCF is originally the mandatory service utilized by the MAC sub-layer, whereas PCF is provided as an optional service with a lower throughput, and as a result is rarely implemented in commercially available WLANs. The ratified DCF in IEEE 802.11 standard is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol (IEEE 1997).

- Statement of the Problem

Performance modeling and analysis has become a necessity in the design and development of computer and communication networks for the purpose of providing the best QoS possible to end users. To this end, accurate analytical models that can capture the real characteristics of network traffics play a pivotal role in maximizing the efficiency data throughput of future network designs.

With ever-increasing demands for multimedia applications and large increase in communication traffic over wireless local area networks in recent years, modeling and analyzing performance metrics of IEEE 802.11 protocol has become an important factor in design, development and throughput optimization of Wireless Local Area Networks.

Developing mathematical models using processes that are incapable of capturing the true characteristics of modern network traffic can lead to unexpected and incorrect results. To obtain an in-depth understanding of the performance characteristics of WLANs, important research efforts have been devoted to developing analytical models for the 802.11 protocol, however, there is a gap in literature to cover the efficient throuhgput of this protocol under realistic network traffic characteristics of burstiness, correlation and self-similarity all combined in one comprehensive model.

- Aim/Purpose of Study

The aim of Modeling Throughput Performance in 802.11 Wireless Local Area Network tends to achieve the following objectives;

1. To build a virtual wireless network using network simulator
2. To develop throughput linear algorithm using MATLAB software
3. To simulate the above linear algorithm using Network simulator and MATLAB for throughput realization
4. To validate the developed techniques with existing techniques

- Significance/Impact of the study

a) Better quality of service
b) Fairness among users in WLAN
c) Reduce congestion in WLAN

- Scope of the Study

The scope of this work includes the techniques to improve the performance of IEEE 802.11 WLAN. The wireless network (WLAN) architecture used in this work is the infrastructure WLAN. The client WLAN and hybrid WLAN are not considered in this work.

- Review of Related Work

A number of studies have emerged on the performance throughput of WLANs using the 802.11 MAC protocol. Some preliminary investigations on the voice capacity of the IEEE 802.11 network have been conducted.

Bellata et al, (2017) determine the optimal number of active STAs that maximizes the system throughput, under the assumption that both MU-MIMO and OFDMA MU are available [9]. Khorov et al. investigate an effective contention window size to balance the transmission opportunities of 802.11ax and legacy stations

Sobrinho and Krishnakumar, (1999) proposed a distributed MAC scheme, called Black burst, with the main goal of minimizing delay for real-time traffic of WLAN 802.11. With this scheme, real-time stations contend for access to the channel in a distributed manner by sending a black burst signal with duration proportional to the time the station has been waiting. After transmitting the black burst, the station listens to the medium for a short period of time, and transmits its pending frame only if the medium is idle. This scheme basically ensures that the longest-waited station transmits a frame without collision.

Choi et al,(2002) Proposed a novel distributed reservation-based MAC protocol that can be used for the enhanced IEEE 802.11 WLAN. The proposed EBA is a simple MAC with a minor modification of the IEEE 802.11 DCF. Since the proposed EBA is backward compatible with the legacy DCF, both EBA and DCF stations can co-exist smoothly in the same WLAN.

Foh and Tantra (2005) proposed an analytical model that improves the model introduced in [42] by relaxing its assumptions. They modeled the effect of post-DIFS (the time slot immediately following the DIFS guard time after a successful transmission). In addition they improved the modeling of the back off freezing mechanism and maximum retry limit specified by IEEE 802.11 standard. But this model assumes that medium access probability depends on whether the previous period is busy or idle which makes the model more complicated.

Ziouva, and Antonakopoulos 2003) modified Bianchi's markov models to calculate the transmission probability of a station that may have different traffic loads, but the proposed model failed to capture some aspects of the standard, e.g. the station enter the back off state if it received a frame when the channel is busy.

An analytical model was proposed by (Conti and Gregori, 2000) to achieve maximum protocol capacity (theoretical throughput limit), by tuning the window size of the IEEE 802.11 back-off algorithms. The main reason why the capacity of the standard protocol is often far from theoretical limit is that during the overload conditions, a station experiences a large number of collisions before its window has a size which gives a low collision probability. It was cited that proper tuning of the back-off algorithm can derive the IEEE 802.11 protocol close to the theoretical throughput limit

II. MATERIALS AND METHODS

Materials

- Laptop with 32-bit operating system
- 4GB Ram
- SSD hard drive
- MATLAB
- Cisco packet

Methods

The method uses to achieve the over mention objectives are, firstly an 802.11 WLAN network was characterized. In this case, carrying out WLAN performance analysis under saturated traffic loading on a practical network could result in the disruption of network operation. Therefore, such an approach may be costly. As a result of this, a modeling approach was adopted. The model was built using advance network simulator. A model will therefore be designed and implemented using MATLAB block-oriented simulation package. Many types of modeling techniques exist; these include descriptive, physical, mathematical, flowchart, schematics, and computer program. A model was developed and simulated using MATLAB/SIMULINK for throughput realization.

802.11 WLAN Architecture

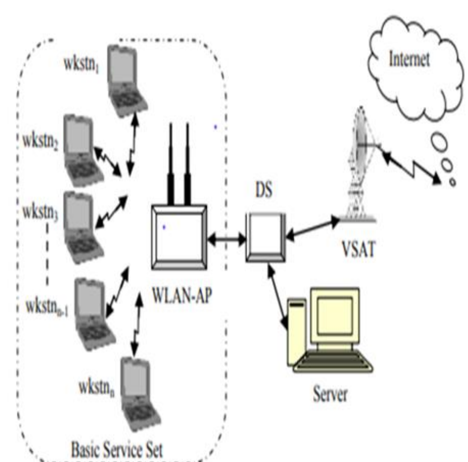


Figure 1 WLAN Infrastructure network

III. SYSTEM MODEL

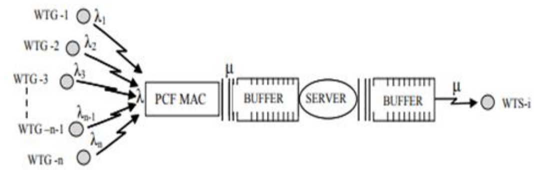
wkstn – Workstation;
WLAN- AP - Wireless LAN Access Point
VSAT - Very Small Aperture Terminal
DS – Distribution System

Figure 1 display the adopted WLAN architecture. The architecture is made of workstations (wkstns), the WLAN access point (WLAN-AP), distribution system (DS), server and very small aperture terminal (VSAT). WLAN infrastructure network is comprised of basic service set (BSS), DS and portals. BSS and the DS are usually referred to as extended service set (ESS). The user terminals (workstations) were linked to the WLAN-AP via the atmosphere wirelessly. The BSS is comprised of the workstations and the WLAN-AP. The geographical extent covered by BSS is referred to as basic service area (BSA). All stations within the BSA can also communicate directly with each other wirelessly. The BSS links the server or the VSAT via the DS while the ESS links the internet via the VSAT. The MAC protocol for the architecture was based on PCF which is usually implemented on infrastructure networks. In PCF mechanism, the stations were under the control of a PC where stations polled for transmission were permitted to deliver and receive MAC service data unit (MSDU). Though PCF and DCF can be implemented in the same MAC, this work was dedicated to only the PCF. The packet generation pattern of the workstations is typically that of bursty ONOFF. The packet generated during the ON period is random and is assumed to have been distributed following Poisson distribution law. The ON and OFF intervals distribution follows the exponential service distribution

802.11 WLAN MODEL

The performance of a WLAN may be defined by the QoS parameters. The QoS parameters considered in the modeling of the WLAN are packet delay, and loss. The two parameters influence the operation of the network and specifically the resource assignment to the traffic load.

The network model was based on an isolated IEEE 802.11 PCF MAC protocol of the network architecture shown in Figure 1. Figure 2, therefore, represents the network model



WTG – Workstation traffic generator
WTS – Workstation traffic sink
Figure 2. Model of PCF WLAN

The WLAN simulation model consists of workstations (source generators and sinks), PCF MAC communication protocol, single server and buffer system. The source generators were intended to generate bursty packets with varied length randomly. The source generators were developed on the basis that packet arrival process is randomly distributed and Poisson in nature with intensity, λ. Also, random exponentially distributed packet lengths were implemented. The server utilization was enhanced by the application of buffering system that controls packet arrivals from the sources and to the sinks. A source transmits packets in bursts when permitted to transmit packets.

The rate of packet transmission (transmission rate) through the wireless medium was represented by μ [bps]. Probes were implemented in the model to gather the necessary data on the desired QoS parameters – packet delay and loss rate. Network packet (pkt) delay was considered as being comprised of packet access delay, propagation and processing delays.

The average delay was processed as expressed in equation 3.1 and 3.2. Network packet loss was considered to consist of packet loss due to access blockage, collision, packet acknowledgment and buffer overflow. The network packet loss rate is defined as the ratio of the number of packets lost to total number of packets offered for transmission during the simulation period (observation time).

$$Mean\ pkt\ delay = \frac{\sum_{i=1}^{n}(\text{value of delay recorded for each packet})}{\text{Number of packets n transmitted}} \quad 3.1$$

$$Packet\ loss\ rate = \frac{Number\ of\ packets\ lost}{Number\ of\ packets\ offered\ for\ transmission} \quad 3.2$$

Developed Simulink

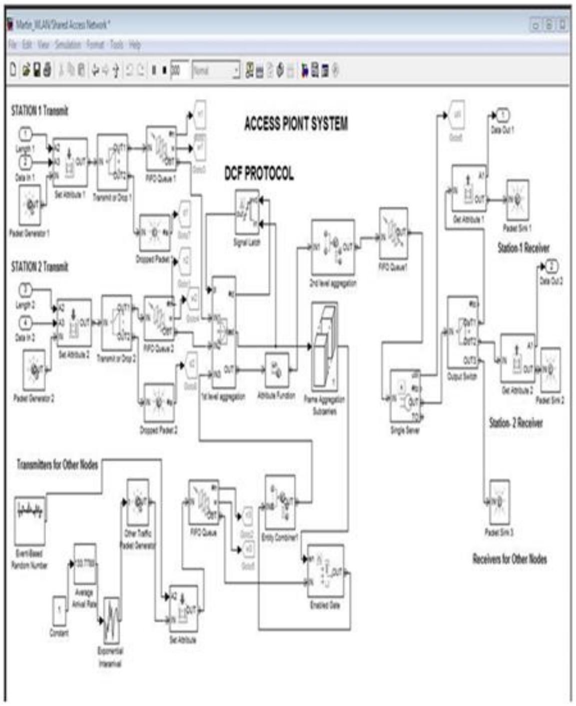


Figure 3 MATLAB/SIMULINK FOR PROPOSED Performance throughput for 802.11 WLAN model

MATLAB provides substantial support for the simulation of TCP and UDP traffic, routing algorithms, queuing algorithms and wide range of logical simulations. The WLAN simulation model consists of sources (generators), DCF MAC module, server and a sink. The sources generate busty packets randomly. The DCF MAC module considered parameters such as arrival rate, binary exponential back-off counter and packet length. The WLAN server was modeled based on the principle of CSMA/CA. The WLAN buffering system serves packets using first-in-first-out queuing discipline. Frame aggregation was provided by the entity combiner and frame aggregation subcarrier as shown in figure 3.2. To simulate the IEEE 802.11 MAC, we set the PHY rate to 2Mbps, 5.5 Mbps and 11Mbps respectively as shown in figure 33 below. Based on the IEEE 802.11b, we assumed that all entities operate at 2.4GHz channel with the same modulation coding scheme

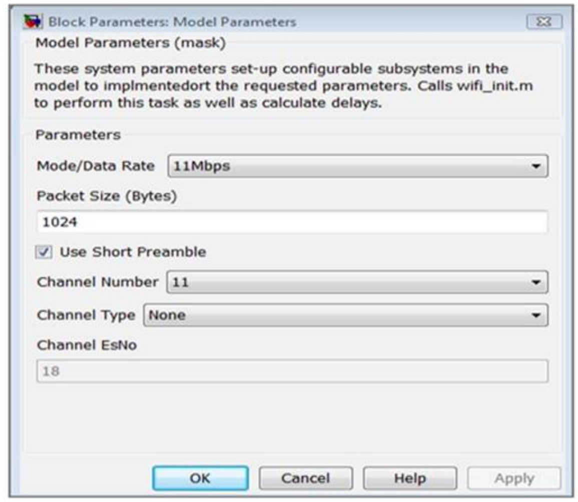


Figure 3 Snapshot of Block parameters showing 11Mbs PHY transmission rate

The Simulation has four scenarios:

Increasing the offered load with variation in the physical rate of 2 Mbps, 5.5 Mbps and 11Mbps respectively.

Simulation for the two-Level frame aggregation mechanisms, frame aggregation Simulation of TCP and UDP traffics.

The TCP and UDP traffic were realized by setting only the fields in connection and connectionless oriented protocols respectively.

For example, UDP does not use Frame Check Sequence and Ack. field for transmission of packets. Each scenario gives analysis of increased load separately for the different frame aggregation mechanism. The CFP during any given repetition interval were strategically positioned in the MATLAB Model to determine the QoS parameters. The parameters used in the simulation will be shown in the Table below.

Simulation Parameters

Table 1 Simulation Parameters.

Parameter	Value	Comments
Data rate	2,5.5,11Mbps	Physical Transmission rates
ACK frame	5Mbs	Acknowledgement frame
aSlotTime	20µsec	Slot time
aDIFSTime	50µsec	DIFS time
aCWmin	31µsec	Min contention window size in unit of aSlotTime
tPLCPPreamble	16µsec	PLCP preamble duration
tPLCPHeader	96µsec	PLCP header duration field
FCS	32bits	Frame Check Sequence

IV. RESULTS AND DISCUSSIONS

- Discussion

To verify the accuracy of the model proposed model, Simulations are carried out in the MATLAB Simulink environment for throughput performance of IEEE 802.11b Network and compared with the actual measurements from real testbed based on the OPNET Modeler. The Simulation results demonstrated that concatenation mechanisms (Frame Aggregation) performed over the MAC sub- layers can actually improve the throughput performance of IEEE 802.11 WLAN by maximizing the bandwidth utilization and reducing the overhead of the IEEE 802.11 MAC. The graph from our Simulations followed the same trend when compared with the work of Quing Ni and that validates the new proposed Model in predicting the network performance.

- Throughput Improvement Analysis

The performance of the proposed MAC level enhancement scheme is evaluated and compared with that of the latest draft of the IEEE 802.11n A-MPDU aggregation schemes. Simulation result shows the different scenarios used in the proposed model strategies. The Proposed scheme is validated using MATLAB simulator and the result of the validation represented in the graph shown

Figure 4. Proposed model Throughput vs. increased offered load

Throughput is the maximum rate at which MAC layer can transmit packets from senders to receivers without packet loss. In figure 4 we can observe that the MAC throughput performance of the schemes with proposed model increases with an increase in the offered load. However, after channel is saturated, the throughput remains constant even when the offered load keeps increasing. This behavior is characterized as normal because of channel saturation, meaning the resources are limited to the impending demand.

Comparing the graph of the throughput of the proposed Model with that achieved by Qiang Ni et al for schemes, the disparity is not much significant, the variance was 2.2%. When the offered load varies from 64Mbps through 128Mbs to 256Mbps, the deviation was 0%, 4% and 1% respectively. This type of disparity may be due to traffic arrival pattern.

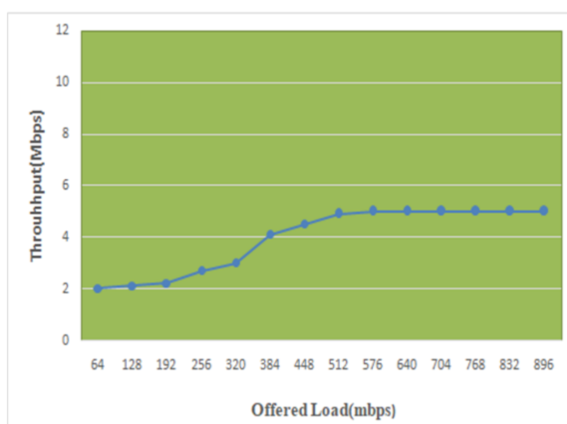


Figure 5. Existing model Throughput vs. increased offered load

The throughput for the existing model cases also increases with the increase of the offered load. However, the maximum achievable throughput is about two times lower than that with proposed scheme.

The throughput with the proposed model is largely due to the effect of overhead which consumes bandwidth as well. When the offered load is between 64mbps to 384Mbps, the deviation varied from 0% to 9%. The disparity results from the facts mentioned before and the variance of the proposed Model to that of Qiang Ni et al is 1.2%.

- Normalized Throughput Performance

As shown in figure above base on simulation, the throughput results with proposed scheme and existing model respectively, where each curve is normalized with the corresponding PHY transmission rate, which is dividing the observed throughput with the corresponding physical rate of 2Mbps, 5.5Mbps and 11Mbps respectively.

From observation in figure 5, First, the maximum normalized MAC throughput differs among different transmission rates. The maximum normalized MAC throughput is about 98% for 11 Mbps, while the maximum relative MAC throughput is less than 60% for 2Mbps. This disparity in the maximum achievable normalized throughput can be explained by noticing that the time for the actual data transmission is relatively shorter when the PHY transmission rate is higher.

Second, the effectiveness of the frame aggregation is high when higher transmission rate is used. For 2 Mbps transmission rate, the slope of the curve is drastically decreased as the frame size increases. On the other hand, for 11Mbps transmission rate, the slope decreasing rate is very low. This observation indicates that for the higher transmission rate, the amount of throughput enhancement gained by the frame aggregation is maintained relatively wider range of payload size.

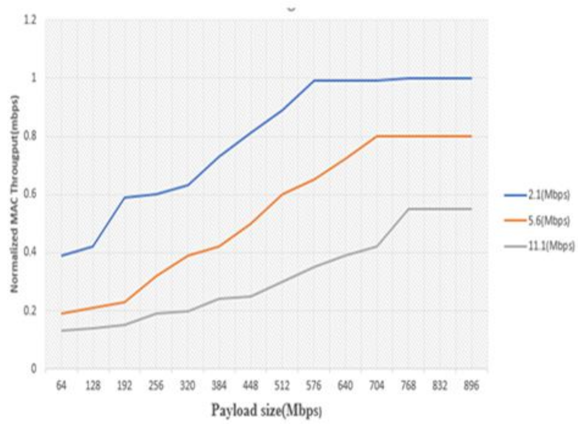


Figure 6. Propose Normalized throughput performance

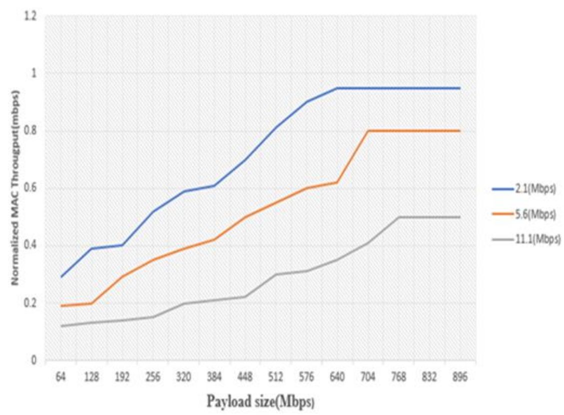


Figure 7. Existing Model for Normalized throughput performance

Base on the simulation on the proposed model and existing model it can be observed that figure 6 and 7 show the throughput performance of all the schemes first increases with an increase of the offered load

CONCLUSION AND RECOMMENDATIONS

- Conclusion

This work analyzed the history and the state-of-the-art efficient MAC level enhancements strategies in IEEE 802.11 WLAN. Overhead was identified as the fundamental problem of MAC inefficiency. Increasing the physical transmission rate alone cannot help a lot as it would lead to more overhead thereby reducing the efficiency of what the technology can offer. Several frame aggregation schemes proposed in the latest IEEE 802.11 draft, namely, A-MSDU, A-MPDU were investigated via intensive and detailed study of aggregation techniques and simulation in MATLAB Simulink environment.

It was also demonstrated that the effectiveness of frame aggregation is high when higher transmission rate is used. Similarly, frame aggregation is very effective in the case of saturated traffic; otherwise, packets have to wait for further packets to arrive which increases delay in the network. From the simulation model, it is evident that the throughput performance of IEEE 802.11 WLAN can be improved by using efficient frame aggregation mechanism. It was shown that the throughput performance depends on a number of parameters which include but not limited to the number of nodes, exponential back-off, physical transmission rate, delay and overhead. These parameters determine the throughput performance of the WLAN.

We therefore conclude from our simulation results that the throughput performance of IEEE 802.11b WLAN can be improved to a maximum throughput of about10.6 Mbps using two-level frame aggregation.

Recommendations

- The effectiveness of proposed model is higher in the case of saturated traffic; otherwise, packets have to wait for further packets to arrive which further increases delay.
- The work recommends in future works that techniques have to be effective even in unsaturated traffic.
- Preferably estimating the time deadline for frame transmission in the queue regardless of whether other frames are available for concatenation.
- In addition, another issue is how large a concatenation threshold should be. Ideally, the maximum value is preferable but in a noisy environment, short frame lengths are preferred because of potential retransmissions if error occurs.
- Future works may include examining frame aggregation performance over error-prone channels and also multi-destination aggregation as we assumed single destination aggregation in our work.

Contributions to knowledge

- The development of throughput linear algorithm using MATLAB software
- The simulation the above linear algorithm using Network simulator and MATLAB for throughput realization

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