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Traffic Offloading in LTE System Based Heterogeneous Networks

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Abstract *The continuous growing developments in the traffic of mobile data limits the data throughput and capacity of cellular networks. "Heterogeneous Networks (HetNets)" are efficient solution to realize such demands. However, in HetNets, the congestion on the overloaded cellular network can be increased when the traffic of data is pushed from a cellular network to the Wi-Fi. In practice, offloading the cellular data traffic to a Wireless Local Area Network (WLAN) depending on the signal quality is a broadly deployed method to solve such problem. The use of Device to Device (D2D) communication further enhances the traffic offloading in WLAN systems and helps to obtain better throughput, end-to-end delay and network load. However, the critical offloading potential and its impacts on the whole performance is not totally understood. In this paper, the offloading of Long Term Evolution (LTE) traffic is presented using a WLAN for voice and video applications. A comparison is performed among two WLAN mechanisms; Distributed coordination function (DCF) and Point Coordination Function (PCF). As well, the effect of adding a D2D technology to the PCF is discussed. The WLAN effectively offloaded nodes at their Signal to Interference and Noise Ratio (SINR) becomes more than a specific threshold. Results presented that the PCF mechanism outperforms the DCF one in terms of packet loss ratio, throughput and the maximum load of the entire network. In addition, the use of a D2D serviced in the PCF helps in further reduction in the network load.*

***Index Terms*—HetNets, offloading, LTE, WLAN, DCF, PCF, D2D, SINR**

I. Introduction

Recently, cellular networks are almost used everywhere. Such networks offer a broad range of efficient services as well as they are continually growing to supply the continuous rising populations. On the other hand, the ability of such networks to achieve the whole expectations of users is a critical issue due to the continuous increasing number of new users and the rising number of multimedia service needs [1].

One more problem is the restricted mobile battery charge, where this problem is considered as a severe limitation of various throughput-hungry applications. The solution of such problems requires efficient modifications in the way of delivering wireless contents. Previously, there are many solutions to such problems focused on enhancing the density of deployment cell. Such solutions reduced the radio links and sizes of cells which offered an efficient bit rates with low energy consumption for uplink communication. On the other hand, the use of a large number of small cells are very expensive and it can increase the interference management complexity [2]. Various alternative approaches were presented earlier to boost the cellular networks competence and meet the increasing needs of mobile data traffics. Generally, the 3rd Generation Partnership Project (3GPP) has proposed efficient LTE features, known as LTE-Advanced. Such features composed of HetNets, Carrier Aggregation (CA) and Cooperative Multi-Point (CoMP) communication. HetNets are recognized by overlaying small cells having low power in a macro-cell coverage region that have high power to enhance the cell splitting gains [3]. In other words, such networks occupy the co-existence of the available macro "Base Station (BS)" dependent cellular networks with an adequate number of small cells that have low power and use similar of various Radio Access Technologies (RATs) [4, 5]. The selection of small cells depended on various factors, as the cell-site place, number of users who must be served and the backhaul capacity availability. As well, such cells can have various properties related to the accessibility and transmission power [6].

In general, a HetNet includes infra-structure points by means of several wireless access technologies having diverse abilities, functionalities and limitations. BSs, such as the Home eNodeBs (HeNBs) are implemented recently to get similar cellular network to the User Equipments (UEs). Such BSs in turn are user deployed or operator deployed, in which they can be located in the same area with a probability to distribute the same spectrum [7].

Several HetNets topics are widely studied in the "Worldwide Interoperability for Microwave Access (WiMAX)" "IEEE 802:16" [8] and 3GPP-LTE [9]. The intelligent offloading of data traffic for deploying small cells is widely proposed and studied in the recent years as a capacity enhancement solution [10]. This paper aims to offload the LTE data traffic using a WLAN with considering voice and video applications. The WLAN deploys both the DCF and PCF mechanisms. A comparison is performed among both mechanisms to evaluate their performance. As well, a D2D technology is included in the PCF. The function of WLAN is to offload nodes that their SINR exceeds a specific threshold.

The rest of the paper includes section II includes a review of some of the recent published researches concerning the paper topic, section III presents an overview of the system under investigation and defines concepts of the 3GPP LTE, WLAN, D2D communication and LTE traffic Offloading using WLAN, section IV discusses the paper methodology, section V presents the developed algorithm stages, section VI analyze the performed simulations, section VII discusses the obtained findings and section VIII summarizes the presented work in this paper.

II. Related Works

In practice, the forcefully offloading of mobile users from macro BSs into small ones, such as the Wi-Fi hotspots can result in decreasing the performance of both the cellular network and users. As an example, a Wi-Fi Access Point (AP) that has efficient signal strength can experience less efficient bandwidth or heavy load, where this in turn decrease its service rate [11]. Conversely, traditional approaches can cause load disparity, which in turn causes reduction in the multimedia applications performance because of the resultant interference via the lightly loaded APs. Such approaches can cause also underutilization of resources [12]. In these cases, any offloading strategy doubter to such conditions is unwanted, where this in turn present the need for adopting efficient offloading strategies.

Ref. [2], investigated the Wi-Fi direct performance as a well-known expertise of D2D communications municipal environments. A wide range of interference levels and D2D loads were covered by the conducted simulation concerning the LTE traffic offloading on a Wi-Fi Direct. In practice, the main focus was on the supported D2D overlay network via a cellular network infrastructure, in which such network offers service detection information to its users to simplify establishing a D2D session. It was revealed that such D2D offloading permits efficient performance enhancement in 4G networks.

Ref. [3], focused on the smallest needed number of Wi-Fi APs to get effective Wi-Fi offloading. This was based initially on set the optimal average per-user throughput with considering that a Wi-Fi network acts as an offloading network for a known cellular network. Depending on such criterion, the smallest needed number of Wi-Fi APs was determined by conducting a mathematical analysis.

An incorporated offloading method was presented in [4] which consider both the network load and signal quality. The main focus was on finding a solution that did not involve modifying the available network designs and standards. The performance of such method was evaluated for various scenarios by conducting various simulations. Results revealed the enhanced user and system performance as a function of throughput.

A method of Radio Access Technology (RAT) offloading was addressed in [14]. The proposed model composed of various RATs, where each one has various tiers of APs. Tiers in turn have various bandwidth, usage density, path loss exponent and transmission power. APs were presented as independent "Poisson points process (PPP)", in which all channels composed of i.i.d. Rayleigh fading channel. After that, the rate allocation through the network was achieved for a weighted association approach, in which weights were tuned to enhance a specific objective. It was found that the best traffic fraction offloaded to enhance the SINR coverage was not general as that enhancing the rate coverage.

Finally, the authors in [5] are presented multi Quality of Service (QoS) responsive 4G/Wi-Fi offloading models to enhance the use of Wi-Fi air interface. This was based on taking into account the loading conditions of the network and keeping the target QoS. Such offloading models were assessed using two 4G/WiFi Multi-RAT test-beds. One of them depended in an actual small cell prototype, while the other one depended on the Opnet network simulator. The evaluation of models performance was illustrated in cheap tradeoff graphs. Such models were able to specify to deploy the WiMAX or offload the traffic to the WiFi depending on the loading data rate of the network.

Therefore, resolving to the complex system level simulations to study and analyze the offloading of LTE traffic is common in the literature. Thus, the goal of this paper is to offload the traffic of LTE traffic using WLAN in a simple and well understood technique.

III. METHODS AND TECHNIQUES

Fig. 1 shows cellular/WLAN integrated network comprising WLAN overlaying in each cell. The cellular access area has a hexagonal structure, where it represents the cellular area. The focus of the analysis is on one cell only with overlaying WLAN, which is known as a cell cluster [15].

In this paper, voice and video application are considered. In addition, the SINR is proposed as a main parameter for users in the downlink for accessing the WLAN.

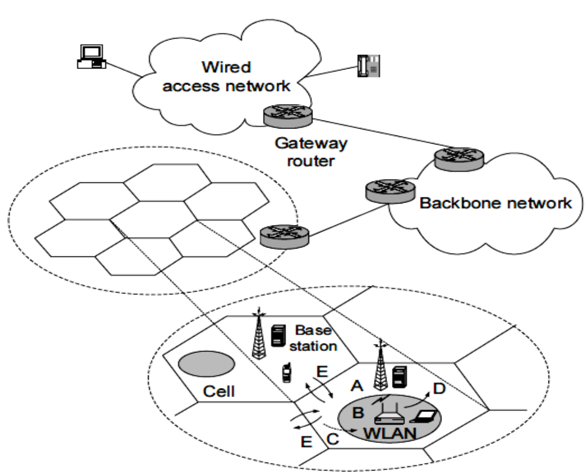

Fig. 1. System Architecture scheduling.

The WLAN in turn can be accessed by users having SINR less than a predefined threshold value.

There are various components included in the IEEE 802.11 architecture. A station is defined as each addressable device with WLAN functionality. On the other hand, APs are entities having further functionality and joined with a Distribution System (DS). Another term is the Extended Service Set (ESS), which stands for the entire WLAN composing of various cells, their respective access points and distribution systems. Many techniques are addressed in this paper which are:

A. 3GPP LTE

Generally, the 3GPP LTE is a modern cellular technology that prospected to trade the used 3G because of its efficient capability [16]. One of the presented3GPP scenarios in [17, 18] is considered in this work with high user density. Such scenario is selected to reconstruct conditions, in which the D2D can be deployed, mainly when cellular networks expose a problem in sustaining the provided load.

The main advantage of the LTE is its ability to offer cheap wide-area coverage, in which the network can be constructed largely with cheap costs. On the other hand, this is not completely regular with considering the perceived user throughputs although for relative fair scheduling. In the presented case in this paper, 20% of users are offered with out-and-out bandwidth of 5 Mbps, in which normal users get data in the range from 256 Kbps to around 11 Mbps. In practice, this is sufficient for Voice over Internet Protocol (VoIP) service, but not for data streaming applications' needs [17, 18].

In the LTE, very complicated signal processing are deployed in the transceiver that is a rather power hungry. This in turn causes poor energy efficiency for lower data rates. Thus, one of the main LTE limitations is that it cannot offer acceptable uplink throughputs to carry out several bit rate-hungry services, as video-on-demand and video conferencing ones. Another limitation is that such network has poor levels of energy competence to maintain large data transmission for large periods of time. Therefore, a suggested efficient solution is the use of a substitute radio technology including higher data rates with an ability to offer attractive energy requirements, as the Wi-Fi.

B. *WLAN topology*

In general, WLAN offers a wireless access for users, where it is widely deployed in various buildings types because of its simple deployment and installation. Such networks depend on the IEEE 802.11 standards as well as they classified as a type of Wi-Fi. WLAN is constructed upon IEEE 802.11 protocol stack [19], where it allows making effective D2D connections in unlicensed bands.

When compared with the LTE, it is a more simple protocol and involves less energy consumption. In addition, it needs less power and smaller links to operate with having more efficient spatial reuse.

Current mobile devices include multiple radio features with both Wi-Fi and LTE interfaces. In this paper, each user has the ability to communicate directly with its related intended users with the use of WLAN. This in turn assists in decreasing the LTE network traffic. The purpose of this work is to decrease the total cellular system traffic using WLAN IEEE 802.11 PCF mechanism.

Practically, entities in the unlicensed bands have no restricted spectrum deployment. Thus, radio resources are not managed using any single entity. Therefore, the implemented radio access technologies to be used for unlicensed bands should be forceful to random interferences. This makes them involved around the random access concept. In WLANs, the mainly used technology is the Wi-Fi. This is due to its ability to work at a short range with high frequencies. Thus, it offers more enhanced data rate, spatial reuse and energy efficiency than those obtained by cellular technologies. [20].

C. *D2D Communication*

The main benefits of the D2D communication are its low transfer delays, enhanced power efficiency and high data rates [21]. The main reasons behind the intensive performed researches concerning the D2D communications deployment in cellular networks including the quickly developing public safety, context aware applications, gaming, multimedia content sharing and voice services. Such applications in turn need location finding and communication between adjacent devices. The accessibility of those features in turn decreases the communication costs.

The D2D functionality has an essential role in the cloud computing of mobile devices and simplifies resources sharing for users including social contents, applications, computational power and spectrum. In addition, the D2D is able to offload the network in local area based on permitting a direct transmission between mobile devices and other ones. The D2D can be also deployed to set-up an unprepared network in a short time with considering it as a substitute for smashed communication infrastructure and network due to natural calamities.

In this paper, the D2D communication is deployed for video sharing among users for a distance less than 40 meters in order to let users get high data rate.

D. *Access Mechanisms*

1) DCF Access Mechanism: The DCF is defined by the IEEE 802.11 standard for WLAN to share an access to the medium depending on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. The DCF includes a fundamental access mode with an elective RTS/CTS access mode. In the fundamental access mode, the channel is sensed by the node to decide if there is data are being transmitted by another node before initiating a transmission request. When the medium is busy, the node postpones its transmission awaiting finishing the present transmission. Thus, it will wait for a further Distributed Inter-Frame Space (DIFS) time and produces an arbitrary back off delay in the range [0 W – 1], where W stands for the contention window. When the medium is inactive for a specific DIFS, the back off timer is reduced. On the other hand, when a transmission is discovered on the medium, it is frozen. Each station transmits its packet when the back off become zero. The SIFS is deployed to offer a priority access for acknowledgement (ACK) packets. When a packet is rceived correctly, the destination node must wait for an SIFS after completing the reception process and sensing an ACK back to the source node to confirm having a correct reception. On the other hand, when there is no received ACK packet in the source node because of transmission errors or collision, the back off algorithm is reactivated after the channel stays inactive for an extended Inter-Frame Space (EIFS) period.

2)PCF Access Mechanism: In the PCF mechanism, the nodes in a Base Station Subsystem (BSS) are polled by the AP. This in turn offers a time separation multiplexing mode for delay sensitive connection oriented services. When such mechanism has to be deployed, the time is segmented into a number of super frames, where each one composed of a contention period with considering a contention period with the DCF use and a Contention-Free Period (CFP) with the PCF use. When the base station transmits a beacon frame with the use of the ordinary DCF access approach, the PCF then begins. Thus, the CFP might be shortened because the base station must compete for the medium. Each station is polled by the PC through the CFP, when such stations are obvious to access the medium. When such operation mode cannot be interrupted by any DCF station, the inter frame space among the PCF data frames is less than the typical DIFS.

IV. Methodology

The aim of this paper is on reducing the load of cellular LTE system through overlaying WLAN systems for voice and video applications. Thus, the IEEE 802.11 standard access mechanism is implemented to access the WLAN to get traffic offloading. WLAN offloads nodes that their SINR exceeds a specific threshold. Two mechanisms are included in the WLAN, namely; PCF and DCF. In practice, the PCF outperforms the DCF one in load and retransmission attempts. In other words, the PCF decreases both the network load and the retransmission attempt. On the other hand, the DCF offers higher packet loss than the PCF due to the contention in the DCF access mechanism. Both the cellular and Wi-Fi systems are used together to drop off the cellular network traffic. Practically, the main concern in such networks is the determination of the optimal number APs needed to get an accepted performance enhancement. Actually, this issue must be addressed since it determines the costs of Wi-Fi network setting up and preservation. Therefore, it decides practicability of such approach for various operators. As well, it stimulates improving and solving problems at various levels of details, including the control of networks, manifold synchronized Wi-Fi accesses, smart caching and improved Wi-Fi usage.

V. Simulation Model

The evaluated performance metrics to analyze the performance of LTE networks due to traffic offloading are the throughput, packet loss ratio and total network load. IEEE 802.11b DCF and PCF mechanisms are presented for traffic offloading on the LTE network with use of WLAN networks. The main algorithm notations and are defined in Table I. Also, the main considered simulation parameters in this work are shown in the Table II. Based on these stages, the flowchart of the algorithm is shown in Fig. 2. The total network load of a system is computed as a product of number of active users and data rate of active users as given by:

TABLE I
ALGORITHM NOTATIONS

NOTATION	DESCRIPTION
BW	BANDWIDTH OF CHANNEL
PL	PATH LOSS
R_X	RECEIVER SENSITIVITY
T_X	TRANSMIT POWER
G_T	TRANSMIT ANTENNA GAIN
G_R	RECEIVED ANTENNA GAIN
SINR	SIGNAL TO INTERFERENCE RATIO
$SINR_{TH}$	THRESHOLD SIGNAL TO INTERFERENCE RATIO
D_{IJ}	DISTANCE BETWEEN USER AND BASE STATION
N	NOISE

TABLE II
SIMULATION PARAMETERS

Simulation Parameters	Value
Number of Users	10, 40, 80, 120, 160, 200
User Transmit Power	24 dBm
Base Station Transmit Power	48 dBm
Wi-Fi Transmit Power	48 dBm
Premium User Bandwidth	5 Mbps
LTE Base Station Capacity	100 Mbps
WLAN radius	3 km
Application	Voice, Video
Data Rate	256 Kbps
WLAN Bandwidth	11 Mbps
SIFS	10 us
SLOT TIME	20 us
DIFS	50 us
ACK	14 Bytes
RTS	14 Bytes
CTS	14 Bytes
DATA Byte	1536 Bytes
Contention Window	20
Maximum D2D Distance	40 m
Access Mechanism	IEEE 802.11 DCF, PCF

$$Network\ Load = N_{users} * R. \quad (1)$$

where N_{users} stands for the number of active users and R is the data rate of user.

The throughput of a system is defined as the number of successful packets received for a given period of time, where it computed using (2).

$$THROUGHPUT = N_{SUCESSFUL}/T. \quad (2)$$

where $N_{sucessful}$ stands for the number of packets received successfully and T is the time.

The packet loss ratio is the ratio of total number of packets dropped to number of packets sent:

$$Loss\ Ratio = Total\ dropped\ packets\ /Total\ send\ packets. \quad (3)$$

A. LTE System without traffic offloading

In this scenario, the traffic offloading is not performed. All the traffic is handled by the LTE base station, which has the capacity to hold traffic of about 100 Mbps. All users are allowed to use either a video or voice application with a bandwidth of 256 Kbps for normal users and premium users with a bandwidth of 5 Mbps.

B. LTE System with traffic offloading using DCF Access Mechanism

In this scenario, the WLAN is used for excess traffic offloading from LTE system. The traffic in excess is offloaded through WLAN. The users with SINR less than a threshold value are offloaded through WLAN.

WLAN uses IEEE 802.11 DCF mechanism to access the channel. Each user senses the channel before transmitting data.

It can access the channel only if it is inactive. Otherwise, the user back off for a random amount of time and then starts sensing again.

C. LTE System with traffic offloading using PCF Access Mechanism

In this scheme, WLAN uses IEEE 802.11 PCF access mechanism to access the channel. The PCF is a centralized polling based mechanism which requires the presence of a base station that acts as PC. The PC in turn polls each station in its polling list with higher priority when they are clear to the access medium. Since each station is scheduled to transmit at a definite time slot, no collision occurs in the PCF.

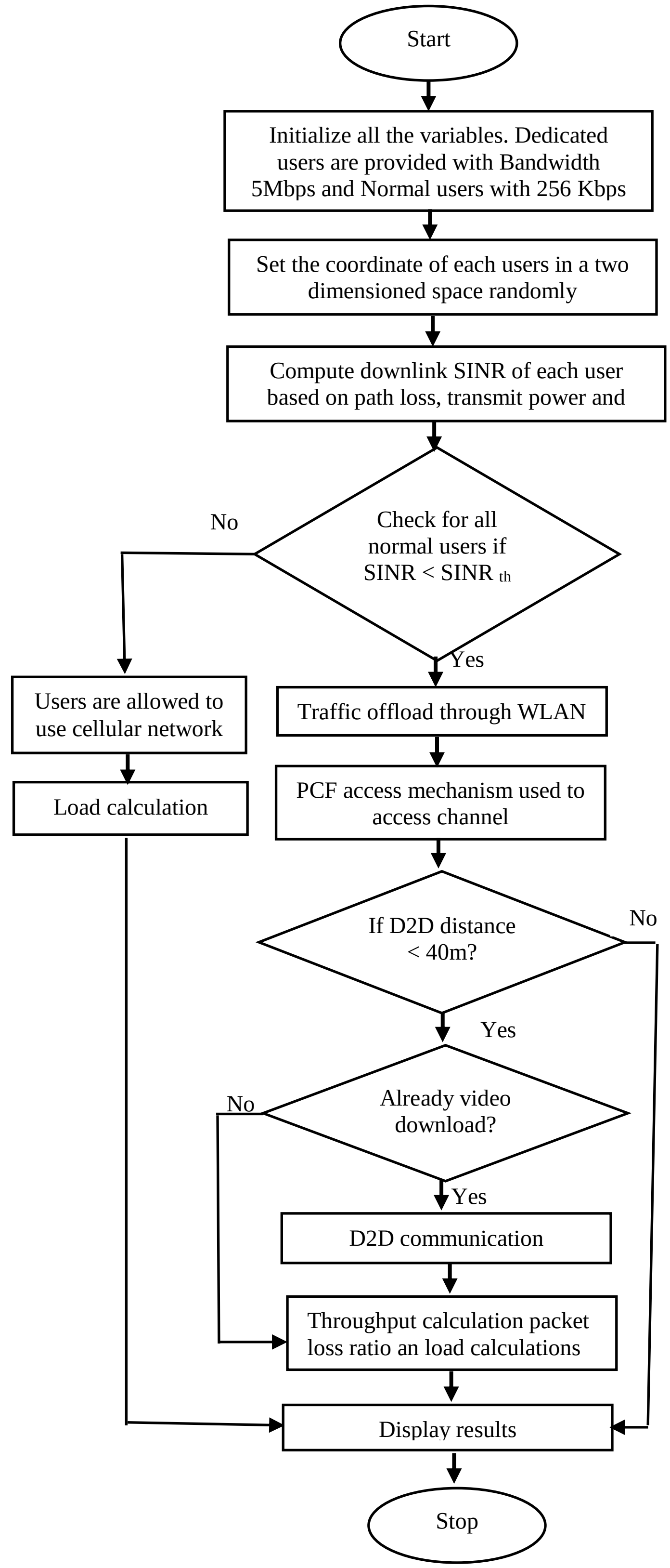

Fig. 2. Algorithm flowchart

In the PCF mechanism, a D2D communication is also used in order to further reducing of the network load. The station stores the video in its cache once downloaded. If other stations try to download the same video with being within the acceptable range and SINR, it can easily download the video from its cache and does not need to download the video from the access point.

VI. SIMULATION RESULTS

Fig. 3 shows the results of total network load with and without traffic offloading. The simulation was run for a time period T and the total network load is calculated. During the simulation time, the whole users are allowed to transmit data to the BS. Since the 20% of users are premium ones provided with dedicated bandwidth of 5 Mbps, the network becomes overloaded when the number of workstation reaches around 50. When number of work station is 50, 40% of users (20 users) are premium ones. Hence premium users provide a load of 100Mbps which is equal to the maximum capacity of the LTE system. Thus, the network cannot accept further load. So figure 3 shows that when the number of workstation is around 50, networks gets overloaded which are then become approximately a straight line at 100 Mbps. This means that no load beyond the maximum capacity can be accepted regardless of the increase in the load.

With the use of WLAN, the stations that have SINR less than the threshold one are offloaded through WLAN, which uses both the DCF and PCF access mechanisms to access the channel. Contention in DCF mechanism drops the packet and increases the load in the base station. As more stations are introduced, a station that cannot continue communication through the LTE base station is allowed to access through WLAN and hence reduces the traffic of the entire system. The polling scheme of Power Control (PC) and the D2D mechanism in PCF access method helps to reduce the load of the entire system.

The packet loss ratio of IEEE 802.11 DCF and PCF access mechanisms is illustrated in figure 4. Based on the figure, the packet loss ratio for the DCF mechanism is higher than that of the PCF one because of its contention based mechanism. This is also because stations are allowed to access the channel only if the channel is inactive; otherwise, stations have to wait for a random period of time for a channel to get free. To avoid the collision, stations have to wait for DIFS and SIFS before they can transmit or receive data. The number of packet losses due to the PCF access mechanism is very small because the PC polls the stations, which have data to be transmitted and are provided with a time slot for transmission. There is a direct relation among the number of stations and the chances of collision, which related to the transmission of data by two or more stations at the same time. This in turn results in a drop of packets. In the PCF access method, the increase in the number of stations is polled by the PC, while the packet loss ratio remains almost the same.

Fig. 5 shows that there is a direct relation between the average end to end delay and the number of nodes. The delay is highest for the DCF mechanism due to the increase in the wait time for users to access a channel.

Due to the high number of users, the access time also increases because of the increase in collision. The PCF mechanism has fairly less end to end delay and remains almost constant because each node shares a fair amount of time to access the channel.

Fig. 6 shows that the average end to end delay increases with the increase in number of nodes. This is since the delay is higher for the DCF mechanism due to the increase in the wait time for users to access a channel.

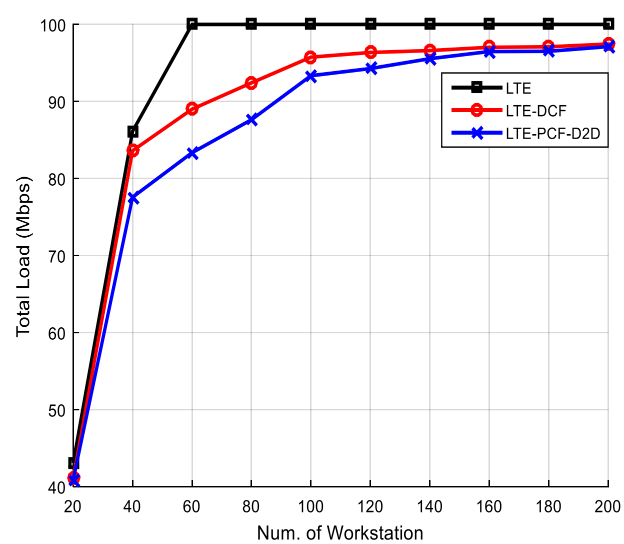

Fig. 3 Total network load

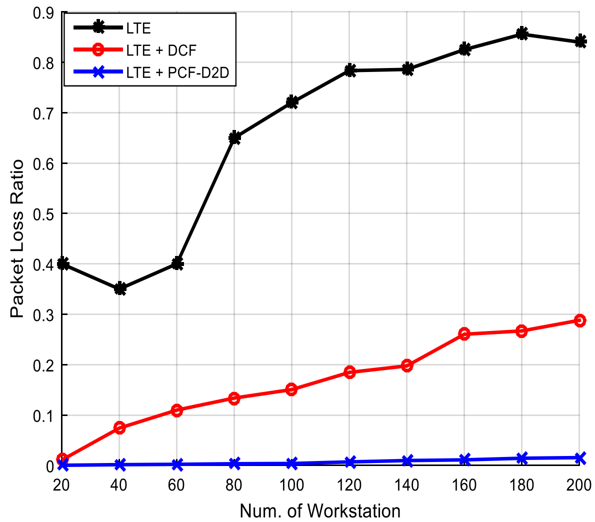

Fig. 4 Packet loss ratio

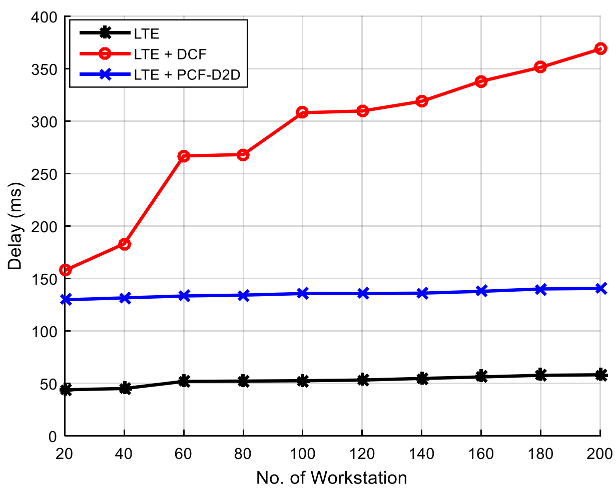

Fig. 5 End to End Delay

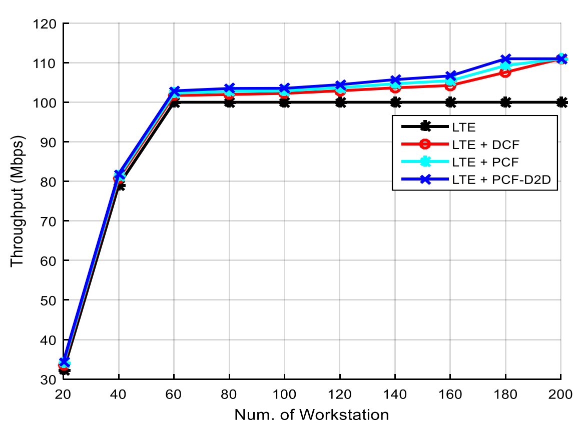

Fig. 6 Throughput

VII. Conclusions

In this paper, an idea of traffic offloading of LTE system through WLAN system is presented. The IEEE 802.11 CSMA/CA is a widely used technique to access channel in WLANs. The LTE system is often overloaded because of the vast amount of traffic. The best solution to offload the overloaded traffic of LTE system is through using WLAN systems, in which stations that have less SINR than a threshold value are allowed to transmit through WLAN systems. The revealed results show that the PCF access method can be effectively used to offload the traffic of the LTE system with reduced loss ratio, enhanced throughput and a decrease in maximum load of the entire network. The addition of D2D services to the PCF access mode helps in further reduction in the network load.

Practically, the key benefit of deploying the D2D communications are enhancing the wireless video networks throughput. The D2D has enhanced spectral efficiency of covered area and improved frequency reuse. Therefore, offloading the transport the majority accepted files to the D2D can free up the BS quickly to allow offering seldom needed video files and several non-video ones. In the future, the presented architecture performance can be assessed using actual traces. This in turn can assist in ranking the effectiveness of the presented approaches and their reliance on the deployed mobility and numerical approaches in the present research.

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