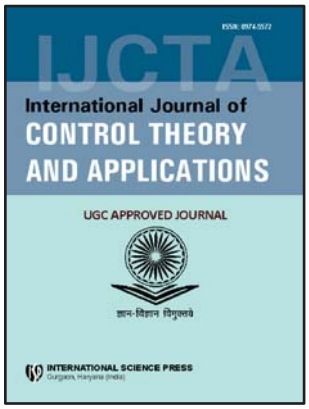

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A Comprehensive Contemplate on Security Aspects of LTE and LTE-Advanced in Wireless Communication Network

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Abstract: Fourth Generation (4G) of wireless communication technology is also noted as LTE (Long Term Evolution). 3GPP (Third Generation Partnership Project) has invented LTE-A (Long Term Evolution – Advanced) by optimizing additional techniques and designs in LTE. Implementation of LTE and LTE-Advanced enhances the security, spectrum efficiency and coverage of wireless network. It also supports higher data usages. Hence, LTE and LTE-Advanced has become one of the most focussed areas for research. A lot of research is happening on various aspects of LTE and LTE-Advanced. Different Protocols and various cryptographic algorithms have been studied to establish the secured communication and to improve the data confidentiality between the users. In this paper, the previous and existing status of LTE and LTE-Advanced will be summarized. The future aspect of LTE and LTE-Advanced with regards to achieving more security will also be explored in this paper.

Keyword: *LTE, LTE-A, Architecture, Security Analysis, TD-LTE, D2D, M2M etc.*

1. INTRODUCTION

Rapid development of wireless communication has brought us to 4G. Due to huge demand and usage of mobile communication, wireless communications have to meet different requirements in concern with data rate, security, data confidentiality etc [1]. Design of LTE is based upon packet, which consist of few elements in the network. Hence, it provides flexible bandwidth selection, high data rate, high spectrum efficiency, low access latency etc [2]. To accommodate maximum number of users for accessing data, LTE optimally selects frequency reuse-1 model which ultimately increases the system capacity and user satisfaction. In addition, LTE and LTE-Advanced also perform interworking with heterogeneous wireless access networks. LTE and LTE-A gives provision of flat IP connectivity as well. Excluding these features in LTE and LTE-A, they have many challenges in regards with security. Hence, security oriented changes have been done in the architecture of LTE and LTE-A [3]. In order to analyze the existing work, some survey papers have already been published. Evolution of various security threats on 4G networks will also be explained in this paper.

When communication is established, FDD (Frequency Division Duplex) and TDD (Time Division Duplex) are the two fundamental duplex schemes. Selection of FDD and TDD affects the uplink - downlink Communication, traffic issues in various directions etc[4]. LTE supports both FDD and TDD duplex schemes.

Hence, in LTE and LTE-A, are able to obtain ultra wide bandwidth, multi-antenna system, ultra high operating frequency etc [5]. TD-LTE (Time Division Long Term Evolution) frame structure is also explained in this paper. With the aim of overcoming of data traffic in cellular network, LTE and LTE-A has built up with secure and smart D2D (Device to Device) communication paradigm. It enables to establish more safe and secured communication between the users [6]. For this, a distinguished design of security framework for UE (User Equipment) D2D communication with detailed procedure is obtained. To obtain the procedure with more security, bandwidth of LTE's cellular network is implemented with more emphasis for control signal flow rather on packet data traffic [7].

Communication in between billions of machines through wired or wireless connection is possible via machine to machine communication. Different security protocols for M2M (Machine to Machine) communication in LTE-Advanced for new authentication and key management have been implemented [8]. To active adequate market penetration, the network must optimize interactions with and between M2M devices [9]. A joint energy saving mechanism has also been implemented for M2M [10]. System Initialization, Membership Update, Mutual authentication and session key agreement are the four phases of any protocol [11]. Hence, in recent years, LTE and LTE-A are considered to be the most advanced and promising technologies in the wireless communication domain. Reduction in the requirement of LTE network is carried out with no effect of user performance due to offloading users. So, it is supporting for offloading mobile data traffic and it also carry out reduction in the load of valid/licensed cellular spectrum of LTE network [12]. Using the concept of GBR and non-GBRs resource reservation, a proper utilization of the resources can be carried out, which will helps to reduce the wasted resources and increases the overall throughput of LTE network [13].

Activation of LTE-CR (Cognitive Radio) can be done by selecting an appropriate threshold load [14]. Various survey has been done on LTE such as of radio resource management for spectrum aggregation and implementation of ICIC techniques in LTE network for the mobile environment parameters etc. [15][16]. Various adaptive techniques have been implemented in advanced 4G cellular network for wideband linear power amplifier, MIMO antenna systems, heterogeneous network and self organising network etc. [17]. LTE and LTE-A have been implemented in various applications such as in LTCC (Low temperature Co-fired Ceramic) process [18], for highly linear and efficient polar transmission [19], for device discovery in cellular network [20], to accurately localize mobile users using aperture radar communication using LTEye [21], multimedia applications [22], future smart living space [23], femtocell applications [24] [25] etc.

This paper elaborates on the various factors of the LTE and LTE-A networks. At the start, emphasise will be on the architecture of LTE and LTE-A. Security analysis will be discussed in third section. Duplex scheme and frame structure of LTE will be explained in fourth section, Implementation of real time security based device to device communication will be note down in fifth section. Open research issues associated with LTE and LTE-A will be focussed in sixth section. Finally, with conclusion paper will be summarized in seventh section.

2. LTE ARCHITECTURE OVERVIEW

As compared to previous generations, LTE has created a niche place for itself in wireless technology because of its architectural advantage. There are various ways to represent architecture of LTE. Rather, one should say that depending upon applications, modifications need to be done in the basic architecture such as Security based architecture, hybrid based architecture, Transport triggered architecture, distributed mobility support based architecture and PON-RAN access architecture [26-30], for time and frequency synchronization etc [31]. In this paper we will emphasis on basic and the simplified model of LTE network architecture.

Figure 1 represents the basic model of LTE architecture. LTE network architecture is simpler. It contains less number of enodes (evolved nodes). Hence, it is one of the reasons that LTE provides high data rates and more security as compared to previous generations. But, it misses out on any radio access control. The bases stations called as enodeB's are attached to core network. The LTE core network is a pure IP based subsystem

without any circuit switch elements. It consists of package data subsystems. It allows entering packed based data. The packet switch core is linked to bundle of data networks such as internet. Voice and multimedia applications require dedicated resources along with specific mechanism to empower them. This would be given by internet protocol multimedia system (IMS). IMS domain establishes a connection in between LTE core network and external telephony network. IMS also plays a vital role in controlling packet data to and from the LTE core network [15].

Usually, the alternative abbreviation for LTE network is given by SAE (System Architecture Evolution). SAE architecture is simply evolution of architecture of 4G network, including core network functionalities. Figure 2 shows the new network entities. The enodeB's are linked to the core network via S1 interface. The base stations are also interconnected with each other via X2 interface. The right side of the figure shows the details of split between a base station eNodeB and Evolved Packed Core Network (EPC). EPC comprises of various elements such as MME (Mobility Management Entity) capital, SGW (Serving Gateway) and the packet data networking. The base stations eNodeB constitutes the E-UTRAN (Evolved UMTS Terrestrial Radio Access Network). There are various functionalities concentrated inside the base stations. The complete protocol stack contain in eNodeB can be shown in the figure such as physical layer, MAC (Medium Access Control) Layer, RLC (Radio Link Control) Layer, PDCP (Packet Data Conversion Protocol) Layer, RRC (Radio Resource Control) Layer.

The base stations hosts functionalities such as dynamic resource allocations, radio admission control, scheduling, connection mobility control, measurement configurations and provision, radio bearer control, intercel RRM (Radio Resource Management) [27]. The mobility management factor on the evolved packet core side hosts the NAS (Non Access Startup security) protocols, idle state mobility handling and EPS bearer control. The surveying gateway provides mobility anchoring. The packet data network gateway establishes a connection with internet and also supports for packet filtering and UE IP address allocation [15] [27].

Below architecture is a basic and generalized architecture of LTE. Depending upon the various applications in the year of 2014 and 2015 to more LTE architecture has been introduced for new unified PON-RAN access for LTE network and for distributed mobility support in SDN bases LTE respectively. These can be explained in detail as follows:

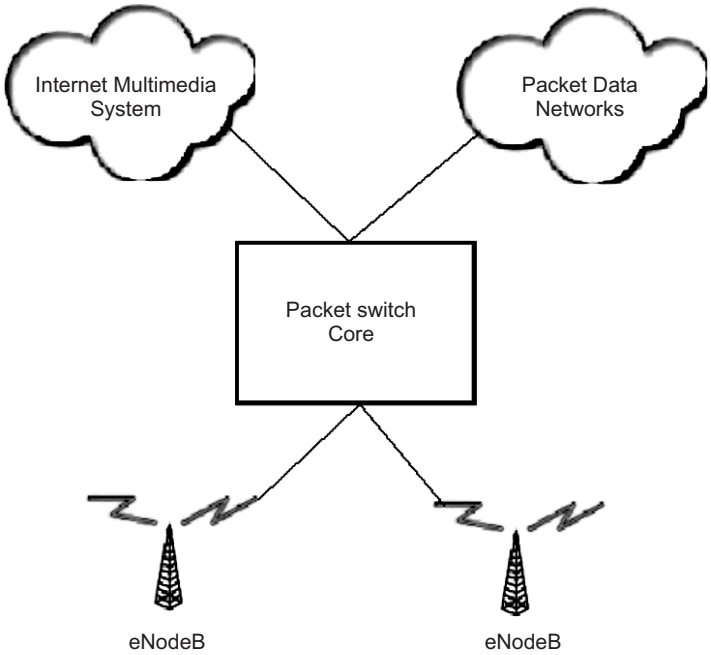

Figure 1: Basic Model of LTE Architecture

2.1. 4G LTE Architecture for New Unified PON-RAN Access

Now a day, LTE is a technology which provides data rate beyond 100 M bites/s per end user. But due to advanced applications, there is more demand of high access bandwidth. Hence, heavy up gradation in the backhaul infrastructure is carrying out by mobile operators with fibre optic deployments to the LTE base stations. Following figure 3 shows the proposed converged architecture of LTE for new unified PON RAN access.Converged architecture consists of EPC (Evolved Packet Core), ONU (Optical Network Unit). eNB (evolved node B), FBG (Fiber Bragg Gratting), OLT (Optical Line Terminal), AGW (Access Gateway), MME (Mobility Management Entity), SGW (Serving Gateway), PGW (Packet Data Network Gateway) etc. [28]

1. **EPC:** All IP core network existing in LTE network architecture is called as EPC. The eNB can be connected to the EPC via s1 interface.
2. **eNB:** In design of eNB, hardware vendors generally use FPGAs or ASICs to implement PHY and baseband processing, DSPs for MAC and RLC protocols and for upper layer of protocol stack CPUs or network processors are used. It is allowed that eNBs should support a common standard interface to interconnect with the ONU. [32]

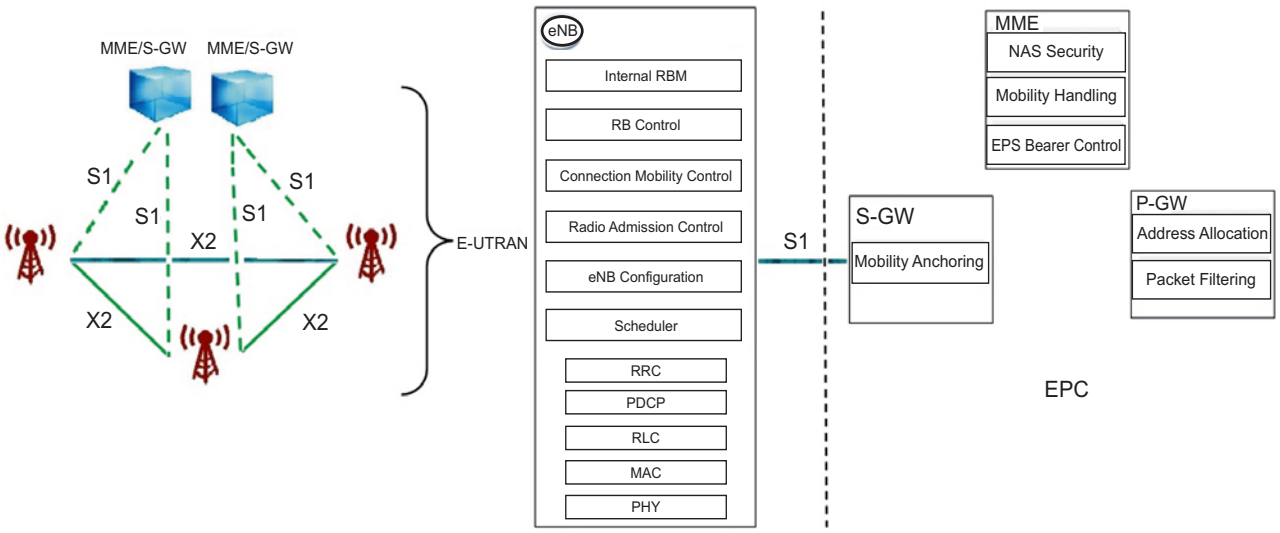

Fig. 2: Detailed Architecture of LTE Network

3. **ONU:** ONU design provides a clear upgrade path to the mobile carriers, since supporting more eNBs would only require adding more line cards to the ONUs. [33]
4. **FBG:** FBG performs the back reflection of λ_{LAN} wavelength from upstream signal heading to the OPT and also allows to recirculate in the architecture. [34]
5. **OLT:** Communication among ONUs can be carried out through OLT. But it is undesirable because it unnecessarily increases delay and wastes capacity of both upstream and downstream channels. [35]
6. **MNE:** The logical components of the EPC, during connections of eNBs to EPC via S1 interface occurs, are called as MME.
7. **AGW:** The serving gateway and packed data network gateway together called as AGW [28].

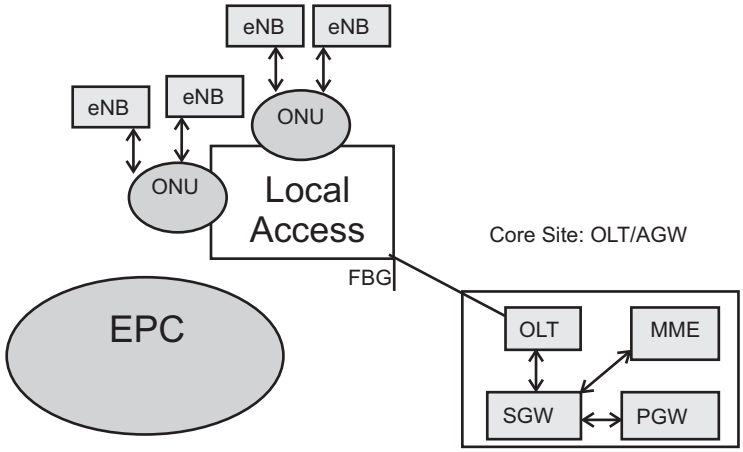

Figure 3: Proposed Converged Architecture of LTE Network

2.2. LTE Architecture for Distributed Mobility Support

In the past few years Smartphone's has rapidly penetrated in the market. Hence, it created a huge mobile data volume. To resolve these kinds of issues a new LTE architecture for distributed mobility support has been invented. Following figure 4 shows the reference model of SDN based DMM (SDMM) architecture in LTE. Majorly architecture consists of E-UTRAN, EPC (Evolved Packet Core), PDN (Packet Data Network), MME (Mobility Management Entity), HSS (Home Subscriber Server), PCRF (Policy Charging Rules Function), UE (User Equipment), P-EGW (PDN Edge Gateway), eNodeB (Evolved Note B) etc. [27]

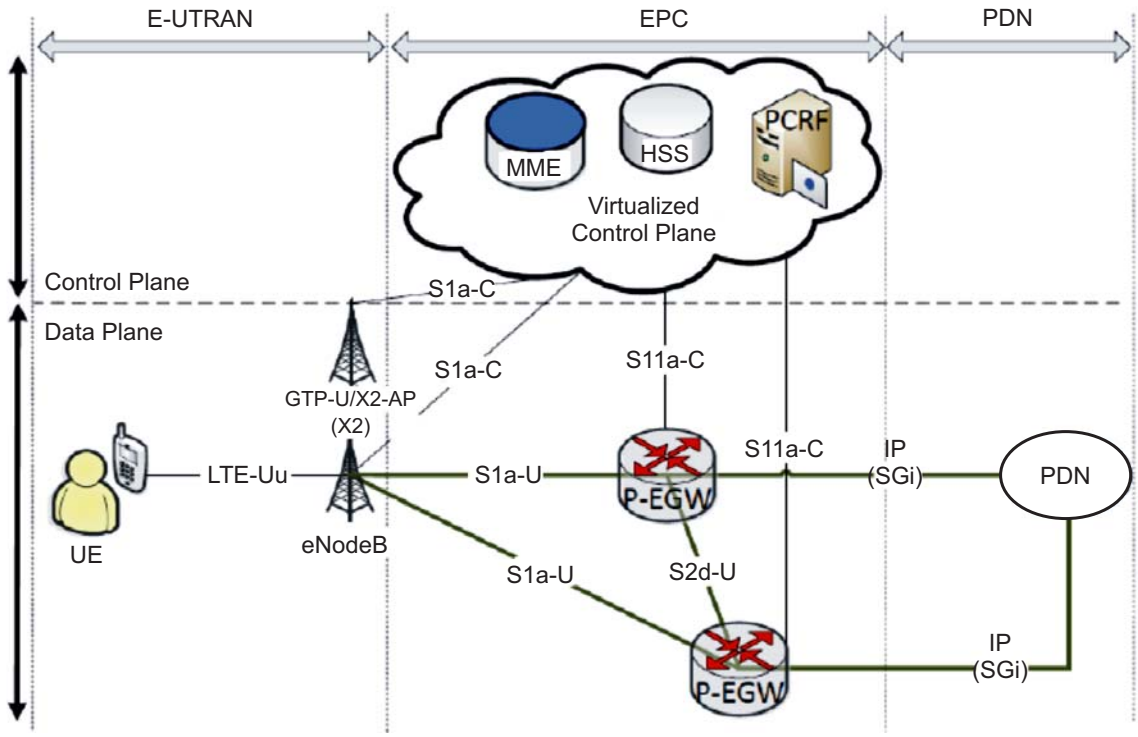

Figure 4: Reference Model for SDN based DMM architecture in LTE [27]

In this architecture, multiple distributed components are implemented in different areas of the network instead of implementing a single centralized infrastructure based on PGW. P-EGW has the same functionality and roles as compared to PGW. But, to keep location of P-EGW in between eNB and SGW, it is deployed near to radio network. It also performs the role of SDN switches to have communication with SDN controller deployed in virtually and centralized control plane. It carries out scalability and flexibility in the LTE network. [26][37]

The virtually control plane incorporates various functions supported by MME, HSS and PCRF. These are the control units in conventional LTE networks. These functions are mostly implemented in the form of cloud systems to perform communications with the entities in data plane through SDN technologies. To separate LTE network data and control planes, SDN technology is used for EPC core networks and edge network. Traffic management is carried out by software instead of hardware routers, due to separation of control and data planes [27] [38].

3. SECURITY ANALYSIS IN LTE NETWORKS

In this section, primarily we will focus on the need of security or requirement of security in LTE, security architecture, protocols, and security threats in LTE. It can be explained as follows:

3.1. Need of Security in LTE

Due to high demand for broadband mobile wireless communication and also to enhance the existing LTE systems to improve speed, for better spectral efficiency, for higher data usage and for lower latencies etc., to achieve all these parameters . It brings to life new challenges related to security. With the enhancement of all above parameters; authentication, data confidentiality, data integrity etc. these parameters also need to maintain so that network will be effective against various malicious attacks, denial of service (DoS) attacks etc. It will also ensure safe mutual authentication among all the nodes, user equipment (UE) and mobility management entity (MME) etc.

3.2. Security Architecture

There are total five security levels in LTE security architecture as indicated in figure 5 and can be explained as below :

1. **Network Access Security:** Mobile equipment (ME), Integrity protection, the E-UTRAN, ciphering between USIM, and the entities in the EPC has been provided by this level. It also powers UES with safe access to EPC.
2. **Network Domain Security:** It gives protection against attacks in the wire line networks and allows nodes to exchange signalling user data and data in a secure manner.
3. **User Domain Security:** Mutual authentication between ME and USIM before USIM access to ME will be provided by user domain security level.
4. **Application Domain Security:** To enable application in UE and to securely exchange messages in the service provider domain, this level is used.
5. **3GPP Domain Security:** It enables UEs to use EPC via non-3GPP access network securely and provide safeguarding security on the radio access link. [2]

3.3. Security Protocols in LTE

Depending upon the real time work concern with the specific application, various protocols have been investigated and analyzed. To perform short term communications mostly if it is based on symmetric cryptography, a symmetric key exchange protocol can be used [39]. Also, it solves the authentication service difficulties with the virtual iterative function [40]. To achieve convergence in 4G, heterogeneous technologies were using internet protocol version 4 (IPv4). After research, it has been analyzed that few of the drawbacks of IPv4 can be mitigated by IPv6. Based on IPv6, one handover protocol known as Noise Resilient Reduced Registration Time Care Of Mobile Internet Protocol (NR_RRTC:MIP) is found out for handover management in 4G [41]. For 4G, Registration Time Care Of Mobile Internet Protocol (RRTC: MIP) is already implemented. NR_RRTC: MIP can be considered as an enhanced version of RRTC: MIP. By studying the stimulation results of both NR_RRTC: MIP protocol provides a better network productivity and also slims down handover latencies as compares to NR_RRTC: MIP [42].

For the security aspect of LTE, to provide the authentication, UMTS/LTE protocols are designed. These protocols mostly serve for the two cases. One is where the mobile stations under attack are statically selected before the execution and the second is where the advisory selects these stations adaptively. This protocol provides a formal security model in LTE [43]. Another aspect of LTE is, for half duplex relay system, in which RN supports with the evolved nodeB and during communication interference cancellation is required [44] [45]. For this purpose, relay protocols can be used such as Amplify and Forward (AF) protocol, Decode and Forward (DF) protocol and Demodulate and Forward (DMF) protocol. Specially, DMF protocol gives better performance as it enhances every symbol power in the weight matrix of the received signal [46]. This protocol also improves the throughput remarkably and ultimately helps to improve the spectrum efficiency of the system as well [47][48].

To provide group based security in machine type communication in LTE advances, different protocols have been proposed. It can be called as AKA (Authentication Key Agreement) protocols. This protocol improves grouping optimisation by aggregating authentication request [49]. Wifi hotspots will be used as a secondary channel to share data among the devices. Hence, this protocol also helps to answer the security problems in M2M (Machine to Machine) communication [50] [51]. Beyond this, few more protocols are also there such as shared segmented upload algorithm (SSU) and a conventional non cooperative method for modelling and simulation in LTE-A [52].

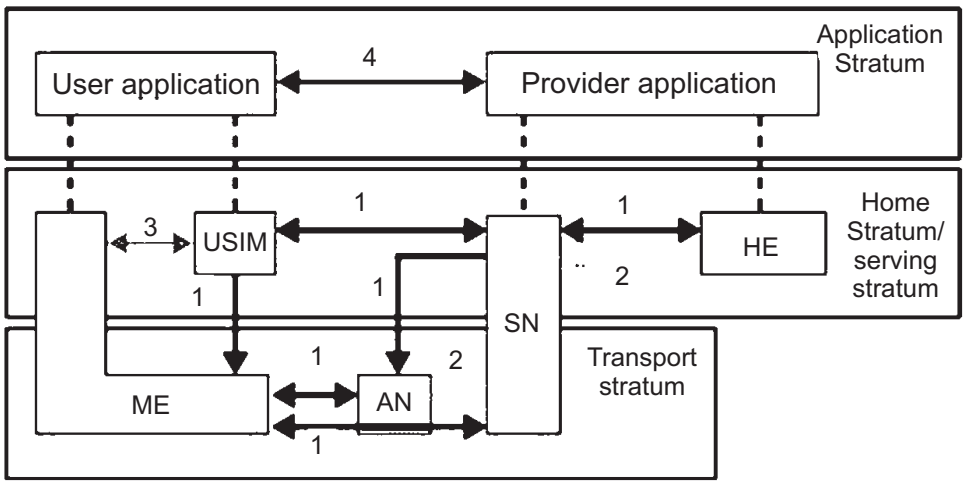

Figure 5: Overview of Security Architecture of LTE Network
(This diagram is referred from http://celtic-san.com/2014/07/24/security/)

The wireless communication technologies are growing throughout the world wide with a booming speed. However, some security threats have been generated which causes different attacks on various generations of wireless communication network. Now a day, for multimedia services, LTE is considered as a best technology due to its feature of faster and safer data transfer. The major threats for LTE are denial of service (DoS) and introduction of rogue node. Physical layer (PHY) and medium access layer (MAC) are mostly attacked by security threats. In physical layer, radio frequency (RF) channels got affected and in MAC layer control messages got affected. Even, attackers may take the charge of Control messages and will also cause a release of all the confidential data [61].

In LTE, DoS is a major security threat which is mostly carried out during initial attachment. When user equipment (UE) sends MAC messages to eNB, it contains plain text [62]. So, it can get easily affected. Also, UE cannot register with the home network during initial attachment. When messages send by UE to eNB with random access preamble, eNB responds to UE with preambleID. If sender and transmitters preambleID will not get matched, it will be considered as unsuccessful. This process will be continues until the maximum limit count will not be obtained. Attackers can easily attack, as this complete process is through plain text only [11].

Systematic study and analysis of security threats in LTE has been done. It can be shown in table 1. There are five different categories for security threats such as LTE architecture, its access procedure, handover attacks, miscellaneous attacks and multihop network security threats [63]. De-synchronization attacks, location tracking, lack of backward security are included under handover attacks [64]. During the process of handover, key will be derived in chaining architecture for target eNB. Hence, easily subsequent keys will be obtained by compromising source eNB. A miscellaneous attack constitutes the unavailability of sequence numbers (SQN), signaling overhead and use of extra bandwidth [65][66]. Rouge RN attack and network coding specific threats are the part of multihop network security threats [29].

Table 1
Security Threats in LTE Network

Category	*Attacks*
LTE System Architecture	Injection, Modification, Eavesdropping Attacks
LTE Access Architecture	DoS/Replay attacks, Privacy Ptoection
Handover Attacks	Lack of backward Security Location tracking De-Synchronization attacks
Miscellaneous Attacks	Lack of SQN, Signaling Overhead, additional bandwidth consumption
Multihop N/W Security Threats	Rogue RN attack, Network Coding Specific Threats

To achieve security and to nullify the effect of threats and attacks various algorithms have also been implemented in LTE such as protected elliptic curve cryptography [67], Steganography [68] turbo decoders [69], and Convolutional turbo coders [70], RSA etc. [71-73]. Some algorithms have also been implemented for enhanced inter cell interference coordination (eICIC) in LTE Hetnets [63]. Study of various security related papers to focus on their advantages and disadvantages has been done and it can be shown through table 2.

4. DUPLEX SCHEME IN LTE NETWORK

In wireless communication system, FDD (Frequency Division Multiplexing) and TDD (Time Division Multiplexing) are the two fundamental duplex schemes. For separate downlink and uplink communications, in paired spectrum, FDD requires two different bands. On the other hand, TDD serves a unique band in unpaired spectrum. To resolve traffic in various directions in time domain, TDD uses UL/DL (Uplink/downlink) sub frames. TD-SCDMA (Time Division Synchronous CDMA) is the numero Uno TDD based technology which implemented smart antenna concept known as beam forming. The continuous up gradation of TD-SCDMA generates TD-LTE (Time Division- Long Term Evolution) and TD-LTEA (Time Division –Long Term Evolution

Advanced). In 4G, for TDD duplex mode TD-LTE standard has been implemented. And for FDD duplex mode, LTE FDD standard has been implemented [74][75]. OFDM (Orthogonal Frequency Division Multiplexing) is introduced by LTE. Together implementation of OFDM and MIMO (Multiple Input Multiple Output) boosted the efficiency of TD-LTE at a drastic level. In addition to this, detailed research influences the better performance of TD-LTE as compared to LTE FDD [5].

There are four parameters to analyze the TD-LTE key technologies such as frame structure, smart antenna technology, and interference coordination and synchronization technique [76]. The frame structure of TD-LTE is quite identical to TD-SCDMA. In TD-LTE frame structure, number of sub frames will be there as shown in figure 6. One radio frame will be of 10ms, further it will get separated into two half frames each of with 5ms. Each sub frame will have the value of 1ms. Again it will get divided in to of 0.5ms. Every sub frame constitutes of downlink sub frame, uplink sub frame and special sub frame [77].

It can be represented as DwPTS, UpPTS and GP as shown in fig. GP is having the configuration of 1 OFDM symbol to 10 OFDM symbols; it can be vary to safeguard the interference of DL to UL [5]. During communication, most operators attempt to enforce access transfers for eSRVCC (enhanced Single Radio Voice Call Continuity). But if the user behavior is very irreregular access transfer should not be exercised [78]. For transmission over LTE/LTE-A network, various resource allocations and scheduling can be optimized so that transmission would be obtained in a flawless manner.

Table 2
Literature Survey

S.No	*Title of Paper with Journal Name*	*Year*	*Publisher*	*Advantages*	*Disadvantages*
1.	A group based security protocol for machine type communication in LTE-advanced. [28]	2016	Springer- Wireless New	AKA protocol Malicious attacks.	Delay parameter Multihop and D2D
2.	Enhancing the security of LTE networks against jamming attacks. [77]	2016	EURASIP Journal on Information Security- Springer	Jamming	Filtration of UL Jamming
3.	Formal analysis of Security procedures in LTE-A Feasibility study [83].	2015	Springer-International Publishing Switzerland	Secrecy weak agreement properties.	Stronger agreement
4.	Formal verification of the Security for Dual connectivity in LTE [76]	2015	IEEE formal methods in s/w engineering	secrecy, agreement freshness of the established key	Full support.
5.	LTE Enhancement for public safety and security Communication to support group multimedia Communication [74].	2015	IEEE network	Multimedia with PMR std	Application specific.
6.	Aware Distributed Security Architecture for 4G multihop wireless network [22].	2015	IEEE Transaction on vehicular technology	Double Authentication	IMS, HONB, MTC security layers of LTE.
7.	Security analysis of Handover key Management in 4G LTE/SAE networks. [75]	2015	IEEE transactions on mobile computing	Signaling load	Handover key management.

S.No	Title of Paper with Journal Name	Year	Publisher	Advantages	Disadvantages
8.	Security enhancement for data transmission in 3G/4G networks. [79]	2015	International conference on computing communication control and automation	Attack resistant	Runtime
9.	Security, reliability in the networks 4G using elliptic curve, irregular LDPC code and interleavers of block. [62]	2015	IEEE latin America transaction	High Reliability	Complex Analysis.
10.	Secure data sharing strategy for D2D communication LTE-Advanced networks. [31]	2015	IEEE transaction of vehicular technology	Secure data. Sharing mechanism.	Offloading
11.	Another Look at Privacy Threats in 3G Mobile Telephony[84]	2014	Springer International Publishing Switzerland	Address threats.	Modifications.
12.	Implementing Curve25519 for Side-Channel--Protected Elliptic Curve Cryptography [61]	2014	ACM Trans. Reconfigurable Technol. Syst.	Authentication Encryption technique	High Cost
13.	Security, Reliability in the Networks 4G, Using Elliptic Curve, Irregular LDPC Code and Interleavers of Block [62]	2011	IEEE Latin America Transactions	Security Reliability	Complexity
14.	Steganography in Long Term Evolution Systems [63]	2014	IEEE	Authentication	Cost, Reliability.
15.	Tail-Overlapped SISO Decoding for High-Throughput LTE-Advanced Turbo Decoders [64]	2014	IEEE Trans. Circuits Syst.	Throughput	Complexity
16.	Rate-Compatible Insertion Convolutional Turbo Codes: Analysis and Application to LTE. [65]	2014	IEEE Transactions on Wireless Communications	Throughput	Authentication, Security.
17.	A Predictive Resource Allocation Algorithm in the LTE Uplink for Event Based M2M Applications [66]	2014	IEEE Transactions on Mobile Computing	Uplink Delay	Security, Reliability.
18.	Message blinding method requiring no multiplicative inversion for RSA [68]	2011	TECS	Security, Power attacks	Data rate

S.No	*Title of Paper with Journal Name*	*Year*	*Publisher*	*Advantages*	*Disadvantages*
19.	Security Enhancement Algorithms for Data Transmission In 4G Networks [79]	2011	International Journal of Advanced Research in Computer Science and Software Engineering	Attack Resistant secure.	High Complexity
20.	A secure wireless communication system integrating RSA, Diffie–Hellman PKDS, intelligent protection-key chains and a Data Connection Core in a 4G environment. [69]	2011	Springer Science, Business Media New York	Privacy, protection Security.	Processing time.

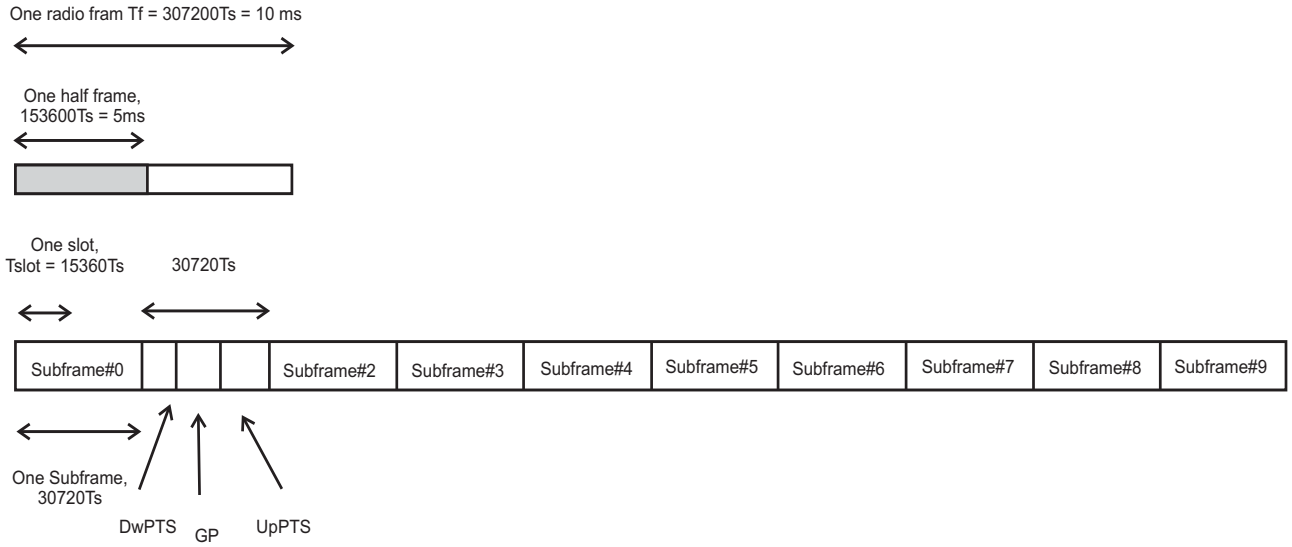

Figure 6: Frame Structure of TD LTE

In LTE, different schedulers are available such as best minimum summation scheduler [79], packet scheduler [80], activity selection based single carrier frequency division multiple access uplink scheduler [81]. The interference management, improvement in gain, data rate etc. can be handled by uplink scheduling [82] [83]. On the other hand, mostly for multimedia streaming over LTE network with hard handoff [84], for standard complaint MIMO scheduling, downlink in LTE is preferred [85].

After TD-SCDMA, TDLTE is the numero uno system which has implemented technology of technology. To achieve diversity gain, spatial multiplexing gain, array gain, coverage enhancement [86], to improve system capacity, to mitigate interference, multi antenna techniques are developed in TDLRTE system. In TD LTE, smart antenna can be bifurcated into single layer beam forming and enhanced multiple layer beams forming. If UE specific reference signal and data are implemented with the same weighting vector at the transmitter, it is called Single layer beam forming. Otherwise, it belongs to multiple layer beams forming. Also, to carry out further improved system capacity and peak throughput, spatial multiplexing techniques can be implemented in combination with multiple layer bream forming [5].

Less interference is the key to improve the system. Hence, now a day's interference cancellation/ coordination plays a vital role to measure the system performance. In TDLTE, to improve the utilization of frequency resource generally single frequency network is implemented. To maximize the cell edge performance, if the reduction of inter cell interference occurs; it's a serious problem in single frequency network. Inter cell coordination techniques can be of two types: Semi Static and Dynamic coordination. Semi static coordination techniques contains ICIC (Inter Cell Interference Coordination) and eICIC (Enhance ICIC) and dynamic coordination techniques contains CoMP (Coordination of Multiple Point) [5].

To avoid interference in between the downlink to uplink, TDD system is obtained as a synchronized system. To carry out synchronization in between the base stations and uplink synchronization among the UE's, LTE system has rigid requirement of synchronization. The stringent synchronization in TDLTE also creates a base for latest technologies such as inter cell interference coordination, MBMS (Multimedia Broadcast Multimedia Services), CoMP techniques etc. [5].

5. DEVICE TO DEVICE COMMUNICATION IN LTE NETWORK

To enhance performance of LTE-A cellular network, D2D communication is a new criterion [87]. Yet D2D communication is established in LTE to obtain secure and smart media sharing, to improve group oriented services, to carry out efficient load balancing, also to set up communication through neighbour discovery etc. D2D communication basically allows communicating two or more mobile devices in adjacency with each other. Within an ad-hoc network, it also provides direct link with physical medium of their choice to perform data transfer. To overcome data traffic congestion in cellular network, security threats and high pricing for data services etc. generates the need of D2D communication. In LTE, during data transfer three major challenges have to be faced such as the huge amount of traffic on the path of radio link from UE to eNodeB, high data traffic price and vulnerabilities [88]. These problems can be overcome by implementing D2D communication. Technology, Business Model and security these three vital aspects need to be considered for the best outcome of D2D communication framework [89-90].

Femtocell access is one of the new technologies for LTE heterogeneous scenarios. It is mostly used for office scenarios where traffic is unevenly distributed [91][92]. A various mechanisms have also been investigated and implemented for opportunistic traffic offloading in 4G such as Scyther, Tamarn and Proverit tools etc. [88]. For self similar traffic LTE has the provision of LTE DRX (Discontinuous Reception) model etc. [93]. A quasi quadrature modulation technique is implemented in LTE mobile network that transmits only a quadrature component of symbols instead of both quadrature and in phase components [94]. Quality assessment of 4G need to be done so that a process running on the terminal can periodically report these parameters to network where they can be process in real time or off line [95]. Also, practical analysis of SNOW 3G generator is carried out in LTE (work in progress) for protecting confidentiality and integrity [96].

There are two different types of D2D services: D2D network assisted and D2D autonomous. In D2D network assisted, network plays a integral role. It performs various functions during communication such as to give location information of devices within a proximity area, to assist information of D2D cluster, to obtain radio link pairing between devices etc. On the other hand, in D2D autonomous, network plays a least role. Because, in this case. It only provides mutual authentication information during communication. Here, devices have to use radio resources autonomously. There are three major security threats in LTE for D2D communication such as fake D2D-S (advertisers), fake D2D-R (recipients) and man in the middle (MITM) attack. Hence, D2D communication framework also tries to overcome these attacks. The detailed framework can be explained further [7].

The proposed D2D communication framework is demonstrated through figure 7. It also illustrates the sequence of task which will be carried out by UE1 and UE2 using MD5 algorithm. It also uses REST/JSON (Representational State Transfer/Java Script Object Notation) services. The whole process is carried out within 1 second to N minutes. It depends upon the size of the file that is going to transfer. In this scenario, operator billing for Appcost and usage of D2D services will be paid by D2D-R. Hence high amount of privacy and legacy will get maintained [7].

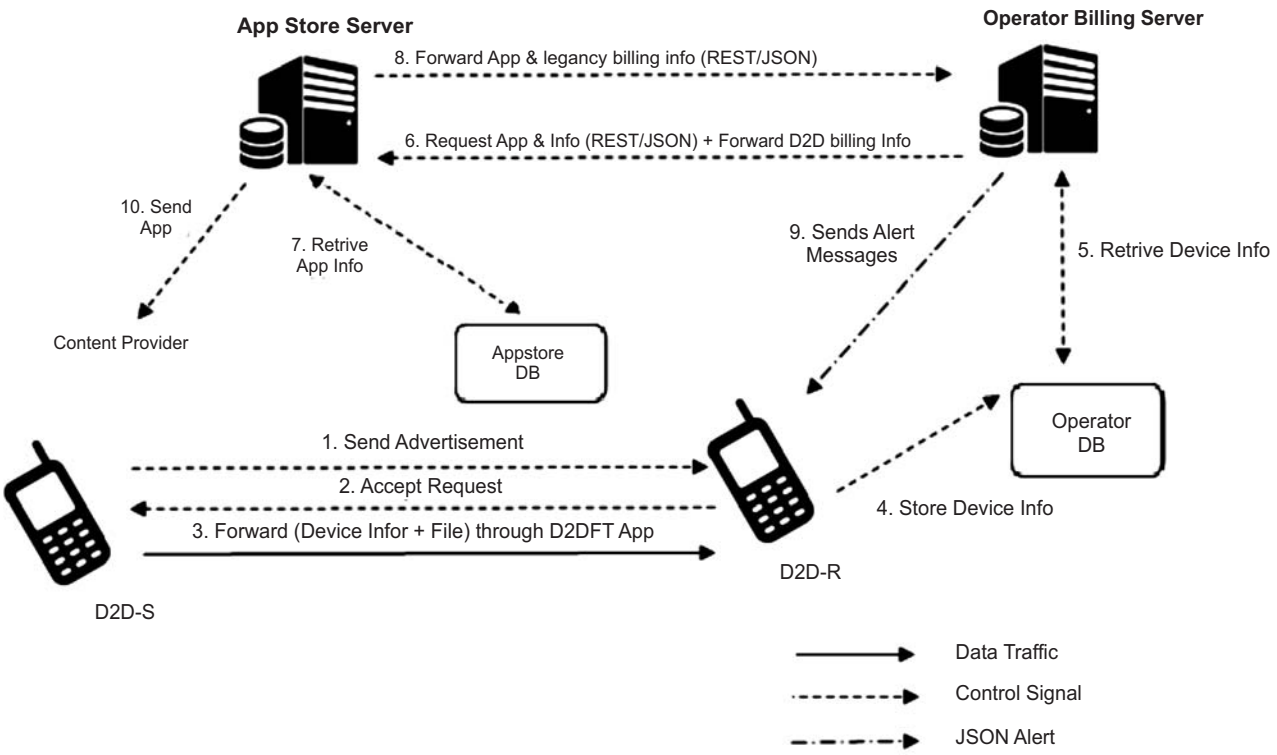

Figure 7: D2D Communication Framework

6. OPEN RESEARCH ISSUES

Various issues of security for LTE/LTE A network can be considered for further research work. Diagrammatic representation of it can be shown through figure 8. The details of every aspects on which sound future work can be carried out, can be discussed as below:

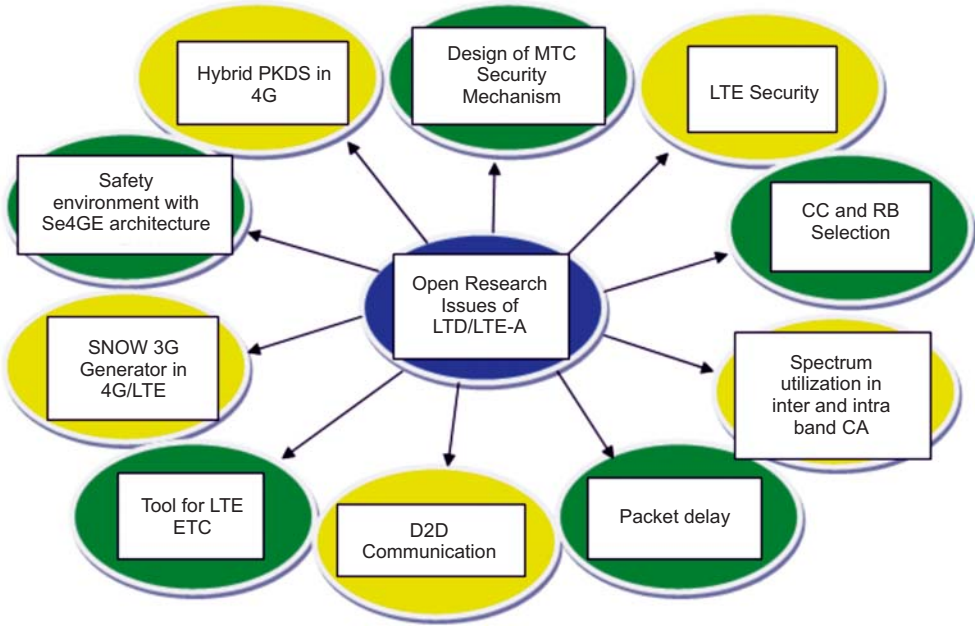

Figure 8: Diagrammatic Representation of Open Research Issues of LTE

6.1. Design of MTC security mechanism

1. In LTE/LTE a development of design of MTC security mechanism is an open research issue. Specifically to improve connectivity speed for confidential data such as in Military purpose, Money transfers, Remote Patient Monitoring, Fire rescue etc. In Military purpose, in war time highly sensitive and secret data is transmitted through various departments and units of an Army. This data needs to be properly encrypted so that the enemy cannot interpret it. If the enemy decrypts the data, it might lead to a defeat in the war.
2. In the past few years, online banking has evolved in a big way. Online transactions have increased enormously. This has increased the need for secure data transfer. As smallest of data leakage or data theft can lead to loss of Billions of rupees. Generally, when sensors are operated as MTC devices, the information will be sent to a MTC application server through 3GPP network. Time is the most critical component when It comes to saving a patient's life. In order to make out the most of the limited available MTC devices can be used during first aid so that the important information about the patient and his condition can be forwarded in advance so that they can do the necessary study and arrangements before needed to be done before treating the patient. This system can save precious life of the patients. Same kind of scenario can also be explained in case of fire rescue. Immediate operation after the breakout of fire is highly expected. So that it can be controlled and managed in an effective manner. In such case data is directly sent through MTC devices, unnecessary delay can be avoided and operation can be carried out effectively. In case of emergency data should be sent by MTC devices to the prespecified person directly so that speed will be improved automatically [13][97]
3. Encryption over head and the quantity of data to be transmitted, these are some of the important parameters to check the system performance and its costs. If the small size transmitting pay load is there, less number if cryptographic operations or encryptions is expected so that automatically security functionality can be achieved. In LTE network, one can work to carry out reductions in the overhead of cryptographic operations so that it will obtain tradeoff between the performance or cost and functionality of the system. For this, the amount of information need to transmit, should also considered [13][98].
4. Various authentication schemes need to be implemented to avoid traffic problems during transmissions. If bulk amount of messages need to be sent, congestion issue will arise. In this case, since large number of messages will be sent to the network at the same time, a signalling over head will also occur. In order to resolve this, different nodes can be activated so that rejection and prevention of the request can be done through them connected at the MTC device. But again it may create a problem that some important message may get delayed or rejected and it will also create some serious impact on the quality of the service for the MTC service users. Hence, alternative solutions to this problem is one can obtain a group of huge number of MNC devices and allow LTE network to handle this group sequentially. It will also solve the access authentication process. But it also contains some drawbacks. Hence, effective and secure design of MTC group to achieve safe authentication process can be considered as an open research issue in the LTE network. [13][99]
5. It is very much required to establish secure communication between the MTC devices. Design for M2M communication model by combining LTE and ad-hoc network is already available. But, due to ad-hoc network large number of threats may attack on to the model. Hence, more efficient and optimised design model as well as protocols are required to handle various threats in the LTE/LTE A networks.[13][98]
6. One can consider two different cases here. One is of restricted mobility and second is of high speed mobility. To support chain high speed mobility and mobility of MTC devices a future work can be carried out. [13][100]

6.2. LTE Security

1. UEs, eNBs and EPC are considered as the most important nodes in the LTE network. Hence, more security is required when the communication is carried out in between UEs, eNBs and EPC. Use of public cryptography has generated inefficiency and less flexibility in LTE network, specifically in handover authentication protocols between HeNBs and eNBs. Hence, it can also be considered as an open issue to perform future research work so that efficiency and compatibility of the network will get boost up. [13][100]
2. When communication is established in between UE and EPC through non 3gpp network, many existing problems are present such as large amount of computation consumption, inherent vulnerabilities etc. hence, it is required to design better system or mechanism which will resolve above issues and will provide safe authentication mechanism. [13][97]
3. Different kinds to attacks can be considered as a major problem for LTE networks. It also creates a problem in key management mechanism, handover authentication procedure etc. to resolve these problems, some handover authentication protocols have been designed such as LTE to WLAN, WiMax/Wifi and GSM/UMTS etc. but still it contains lot of lacunas and hence needs to be more researched. [13][97]
4. Specifically, for the LTE security mechanisms need to be created in the architecture to conserve communication between UEs, eNBs and EPC so that the attacks by traditions protocols can be avoided. Also, some authentication and confidentiality architectures ought to be considered to accomplished safe seamless handover authentication protocols among various nodes.
5. For the IP multimedia system, to resolve authentication process, to prevent denial of service attacks and malicious attacks in the LTE network, a robust authentication mechanism can be designed. [2][22]
6. LTE network has also got badly affected due to lack of back word secrecy, synchronization and rogue RM attack. But yet no more investigation is done on these topics. Hence, need to perform research on these attacks.

6.3. Carrier Component (CC) and Resource Block (RB) Selection

Proper selection of CCs can generate various positive aspects such as improvement in quality of service for different traffic classes, high throughput, equality in various categories of UEs, deployment scenarios. Once selection of CC is done; function of RB is to allocate available resource blocks to the capital UEs. Optimal selection of RB also leads to increase in the spectral efficiency. So with CC how to perform RB selection should also get investigated. [15]

6.4. Spectrum utilization in inter and intra band carrier aggregation (CA)

One needs to consider different parameters such as channel characteristics, performance of retransmission to decide CC selection. On the other hand, in intra bands CA, spectral efficiency can be improved using the bands between the CCs. Further investigation is expected on the guard bands. [15]

6.5. Packet delay

Scheduling algorithm plays a vital role in determining how the associated resources will get utilized. Efficient scheduling algorithm uses the resources effectively and simple scheduling schemes waste the system resources. In both the cases, packed delay plays important an important role to achieve high data rate, low latency etc. hence, packed and application delay knowledge will be the demand of future mobile system [15].

6.6. D2D communication

1. **Mode Selection:** The capital D2D devices can operate in various modes such as silent mode, dedicated mode, cellular mode etc. one more type of mode exists which is for control and data packed. But still, research is required to decide level of assistance required form the network. [16]
2. **Group Formation:** In D2D, communication can be established through various ways such as unicast, multicast, broadcast etc. although, how the group formation can be done, this aspect can be considered as an open challenge. Also, depending upon the number of devices in the group how throughput will depend is an unanswered question. [16]
3. **Interference and resource management:** In D2D communication, as number of devices will be part of communication, interference and resource management are crucial parameters. To improve of quality of service of the system, yet some sources are required to mitigate the issues generated due to interference and resource management.
4. **D2D based multihop communication:** If multihop communication Is established between D2D, then intermediated D2D will act as a relay, so here problems need to be analyzed in the context of D2D. [16]

6.7. Tool for LTE ETC

In data and controlled traffic model an efficient design of tool LTE EPC is expected. Due to this, various parameters such as signalling transactions, throughput can be predicted. [35]

6.8. SNOW 3G Generator in 4G/LTE

In LTE, SNOW 3G generator is used for protecting confidentiality and integrity. It also helps to improve the efficiency of the network. Light weight version of SNOW 3G Generators for devices will less number of resources with analysis of several theoretical properties of the generator should get analysed in future. [42]

6.9. Safety environment with Se4GE (Security System for a 4G Environment) architecture

Se4GE is a LTE based system that integrates the RSA and Diffie-Hellman algorithms to solve some of LTE-A's security drawbacks. In the future it is expected to develop Se4GE architecture with less number of steps but with same amount of security so that time will be minimised. Also, the design of Se4GE architecture for various applications such as eBooks, ewallet, and ecommerce is expected. [69]

6.10. Hybrid PKDS (Public Key Distribution System) in 4G

In LTE/4G, hybrid PKDS is already implemented. But to implement this system for real time wireless network is an open research topic. Also, the system can the implemented for video, voice and image. Integration of PKDS with various compressions algorithms can also be obtained to achieve more scalability of the system. [78]

7. CONCLUSION

In this paper, architecture, security threats, duplex scheme, D2D communication and security protocols in LTE have been overviewed. Extensively, basic and detailed architecture of LTE network is discussed. Depending upon our future applications, architecture of LTE could be modified. A survey of threats and attacks for LTE has been explained in this paper. According to threats and attacks generated for LTE, in recent future a necessary changes could be obtained in the duplex scheme and also in the D2D communication framework, So that, a communication in LTE network will be more secure, confidential and faster. As per the requirement of specific application, various protocols have been investigated. These protocols also summarized in this paper. In future, to carry out better security in the LTE communication network, further work can be carried out. It will ultimately make LTE network more flexible and efficient.

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REFERENCES

[1] I. Akyildiz, D. Gutierrez-Estevez, R. Balakrishnan and E. Chavarria-Reyes, "*LTE- Advanced and the evolution to Beyond 4G (B4G) systems*", Physical Communication, vol. 10, pp. 31-60, 2014.

[2] J. Cao, M. Ma, H. Li, Y. Zhang and Z. Luo, "*A Survey on Security Aspects for LTE and LTE-A Networks",* IEEE Communications Surveys & Tutorials, vol. 16, no. 1, pp. 283-302, 2014.

[3] J. Gozalvez, "*South Korea Launches LTE-Advanced [Mobile Radio*]", IEEE Veh. Technol. Mag., vol. 9, no. 1, pp. 10-27, 2014.

[4] G. Gómez, Q. Pérez, J. Lorca and R. García, "*Quality of Service Drivers in LTE and LTE-A Networks*", Wireless Pers Commun, vol. 75, no. 2, pp. 1079-1097, 2013.

[5] S. Chen, S. Sun, Y. Wang, G. Xiao and R. Tamrakar, "*A comprehensive survey of TDD-based mobile communication systems from TD- SCDMA 3G to TD-LTE(A) 4G and 5G directions*", China Communications, vol. 12, no. 2, pp. 40-60, 2015.

[6] L. Militano, M. Condoluci, G. Araniti, A. Molinaro and A. Iera, "*When D2D communication improves group oriented services in beyond 4G networks*", Wireless Netw, vol. 21, no. 4, pp. 1363-1377, 2014.

[7] S. Ramasubramanian, s. chung, S. Ryu and L. Ding, "*Secure and Smart Media Sharing Based on a Novel Mobile Device-to-Device Communication Framework with Security and Procedures*", ACM, pp. 35-49, 2015.

[8] F. Ghavimi and H. Chen, "*M2M Communications in 3GPP LTE/LTE-A Networks: Architectures, Service Requirements, Challenges, and Applications*", IEEE Communications Surveys & Tutorials, vol. 17, no. 2, pp. 525-549, 2015.

[9] J. Poncela, J. Moreno-Roldan, M. Aamir and B. Alvi, "*M2M Challenges and Opportunities in 4G*", Wireless Pers Commun, vol. 85, no. 2, pp. 407-420, 2015.

[10] L. Sun, H. Tian and L. Xu, "*A Joint Energy-Saving Mechanism for M2M Communications in LTE based System*", IEEE, pp. 4706- 4711, 2013.

[11] M. Khan and C. Mitchell, "*Another Look at Privacy Threats in 3G Mobile Telephony*",Springer, pp. 386-396, 2014.

[12] D. Hagos, "*The performance of network-controlled mobile data offloading from LTE to WiFi networks*", Telecommunication Systems, vol. 61, no. 4, pp. 675-694, 2015.

[13] S. Albasheir and M. Kadoch, "*Enhanced Control for Adaptive Resource Reservation of Guaranteed Services in LTE Networks*", IEEE Internet of Things Journal, vol. 3, no. 2, pp. 179-189, 2016.

[14] L. Liu, Y. Zhou, L. Tian and J. Shi, "*CPC-based backward-compatible network access for LTE cognitive radio cellular networks*", IEEE Commun. Mag., vol. 53, no. 7, pp. 93-99, 2015.

[15] M. Yassin, M. AboulHassan, S. Lahoud, M. Ibrahim, D. Mezher, B. Cousin and E. Sourour, "*Survey of ICIC techniques in LTE networks under various mobile environment parameters*", Wireless Network, 2015.

[16] H. Lee, S. Vahid and K. Moessner, "*A Survey of Radio Resource Management for Spectrum Aggregation in LTE-Advanced*", IEEE Communications Surveys & Tutorials, vol. 16, no. 2, pp. 745-760, 2014.

[17] B. Hätty, H. Dreßler, H. Kröner, G. Schnabl, M. Schopp and A. Splett, "*Adaptive techniques in advanced 4G cellular wireless networks*", EURASIP Journal on Advances in Signal Processing, vol. 2016, no. 1, 2016.

[18] Li-Ju Chen and Ken-Huang Lin, "*Implementation of a Compact EMI Filter Array for 4G-LTE Applications on LTCC*", IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 5, no. 6, pp. 713-722, 2015.

[19] K. Liang, H. Yang, C. Chang and J. Chen, "*A Wideband Pulse-Modulated Polar Transmitter Using Envelope Correction for LTE Applications*", IEEE Transactions on Microwave Theory and Techniques, vol. 63, no. 8, pp. 2603-2608, 2015.

[20] K. Yang, M. Wang, K. Zou, M. Hua, J. Hu, J. Zhang, W. Sheng and X. You, "*Device discovery for multihop cellular networks with its application in LTE*", IEEE Wireless Commun., vol. 21, no. 5, pp. 24-34, 2014.

[21] P. Lin and Y. Lin, "*An IP-based packet test environment for TD-LTE and LTE FDD*", IEEE Commun. Mag., vol. 52, no. 3, pp. 97-103, 2014.

[22] B. Levasseur, M. Claypool and R. Kinicki, "*Impact of Acknowledgments on Application Performance in 4G LTE Networks*", Wireless Pers Commun, vol. 85, no. 4, pp. 2367-2392, 2015.

[23] T. Wu, D. Chung, C. Chen and H. Chao, "*Pave the way to future smart Living Space-Cross layer Enhanced AAA for 4G core Network*", IEEE, 2007.

[24] J. Chen, C. Chang and H. Yang, "*Linearity Enhanced Wide-Bandwidth Pulse-Modulated Polar Transmitters for LTE Femtocell Applications*", IEEE Transactions on Microwave Theory and Techniques, vol. 64, no. 1, pp. 219-225, 2016.

[25] K. Zheng, X. Zhang, Q. Zheng, W. Xiang and L. Hanzo, "*Quality-of-experience assessment and its application to video services in lte networks*", IEEE Wireless Commun., vol. 22, no. 1, pp. 70-78, 2015.

[26] O. Anjum, M. Ali, T. Pitkänen and J. Nurmi, "*Transport triggered architecture to perform carrier synchronization for LTE*", TECS, vol. 13, no. 4, pp. 1-15, 2014.

[27] Y. kim, H. Lim, K. Kim and Y. Han, "*A Distributed Mobility Support in SDN-Based LTE/EPC Architecture*", Springer, 2015.

[28] K. Ramantas, K. Vlachos, A. Bikos, G. Ellinas and A. Hadjiantonis, "*New Unified PON-RAN Access Architecture for 4G LTE Networks*", Journal of Optical Communications and Networking, vol. 6, no. 10, p. 890, 2014.

[29] P. Rengaraju, C. Lung and A. Srinivasan, "*QoS-Aware Distributed Security Architecture for 4G Multihop Wireless Networks*", IEEE Trans. Veh. Technol., vol. 63, no. 6, pp. 2886-2900, 2014.

[30] S. Ucar, S. Coleri Ergen and O. Ozkasap, "*Multi-Hop Cluster based IEEE 802.11p and LTE Hybrid Architecture for VANET Safety Message Dissemination*", IEEE Trans. Veh. Technol., pp. 1-1, 2015.

[31] A. Golnari, M. Shabany, A. Nezamalhosseini and G. Gulak, "*Design and Implementation of Time and Frequency Synchronization in LTE*", IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol. 23, no. 12, pp. 2970-2982, 2015.

[32] N. Abu-Ali, A. Taha, M. Salah and H. Hassanein, "*Uplink Scheduling in LTE and LTE-Advanced: Tutorial, Survey and Evaluation Framework*", IEEE Communications Surveys & Tutorials, vol. 16, no. 3, pp. 1239-1265, 2014.

[33] W. Fernandez, F. Jara and O. Hormazabal, "*Security, Reliability in the Networks 4G, Using Elliptic Curve, Irregular LDPC Code and Interleavers of Block*", IEEE Latin America Transactions, vol. 9, no. 1, pp. 792-797, 2011.

[34] S. Deb, P. Monogioudis, J. Miernik and J. Seymour, "*Algorithms for Enhanced Inter-Cell Interference Coordination (eICIC) in LTE HetNets*", IEEE/ACM Transactions on Networking, vol. 22, no. 1, pp. 137-150, 2014.

[35] P. Kanani, V. Kaul and K. Shah, "*Hybrid PKDS in 4G using Secured DCC*", IEEE, pp. 323-328, 2016.

[36] M. Taranetz, T. Blazek, T. Kropfreiter, M. Muller, S. Schwarz and M. Rupp, "*Runtime Precoding: Enabling Multipoint Transmission in LTE-Advanced System-Level Simulations*", IEEE Access, vol. 3, pp. 725-736, 2015.

[37] Y. Choi, Y. Seong, Y. Yoo, S. Lee, M. Velazquez Lopez and H. Yoo, "*Multi-Standard Hybrid PLL With Low Phase-Noise Characteristics for GSM/EDGE and LTE Applications*", IEEE Transactions on Microwave Theory and Techniques, vol. 63, no. 10, pp. 3254-3264, 2015.

[38] S. Wong, Q. Huang, G. Sun, L. Zhu and Q. Chu, "*Multiple-Mode Wideband Dual-Polarized Antenna for Long Term Evolution (LTE) Application*", Antennas Wirel. Propag. Lett., vol. 15, pp. 203-206, 2016.

[39] A. Gomes and T. Braun, "*Feasibility of Information- Centric Networking Integration into LTE Mobile Networks*", ACM, pp. 627-633, 2015.

[40] S. Bhaskar, G. Satish Kumar and P. Ramana Reddy, "*Design and analysis of an adaptive handover protocol for 4G networks*", Journal of Shanghai Jiaotong University (Science), vol. 20, no. 2, pp. 209-217, 2015.

[41] R. Sathya, V. Venkatesh, R. Ramji, A. Ramamurthy and B. Tamma, "*Handover and SINR Optimized Deployment of LTE Femto Base Stations in Enterprise Environments*", Wireless Pers Commun, 2016.

[42] M. Lee, N. Smart, B. Warinschi and G. Watson, "*Anonymity guarantees of the UMTS/LTE authentication and connection protocol*", International Journal of Information Security, vol. 13, no. 6, pp. 513-527, 2014

[43] S. Malik, S. Moon, B. Kim, C. You, H. Liu and I. Hwang, "*Design and Analysis of an Interference Cancellation Algorithm for AF, DF and DMF Relay Protocol in Multiuser MIMO Scenario Based on the LTE-Advanced System*", Wireless Personal Communication, vol. 75, no. 1, pp. 775-797, 2013.

[44] J. Chen, C. Yang and Y. Mai, "*A novel smart forwarding scheme in LTE-Advanced networks*", China Communications, vol. 12, no. 3, pp. 120-131, 2015.

[45] Y. Li, L. Liu, H. Li, J. Zhang and Y. Yi, "*Resource Allocation for Delay-Sensitive Traffic Over LTE-Advanced Relay Networks*", IEEE Transactions on Wireless Communications, vol. 14, no. 8, pp. 4291-4303, 2015.

[46] Y. Yin, Y. Gan, H. Wen and T. Li, "*A symmetric key exchange protocol bsaed on virtual S-box*", China Communications, vol. 11, no. , pp. 46-52, 2014.

[47] R. Park, H. Jung, K. Chung and K. Kim, "*Performance analysis of LTE downlink system using relay-based selective transmission*", Pers Ubiquit Comput, vol. 18, no. 3, pp. 543-551, 2013.

[48] K. Chen, B. Natarajan and S. Shattil, "*Secret Key Generation Rate With Power Allocation in Relay-Based LTE-A Networks*", IEEE Trans.Inform.Forensic Secur., vol. 10, no. 11, pp. 2424-2434, 2015.

[49] C. Han and H. Choi, "*Security Analysis of Handover Key Management in 4G LTE/SAE Networks*", IEEE Transactions on Mobile Computing, vol. 13, no. 2, pp. 457-468, 2014.

[50] D. Choi and H. Choi, "*An Group-based Security Protocol for Machine Type Communications in LTE-Advanced*", Journal of the Korea Institute of Information Security and Cryptology, vol. 23, no. 5, pp. 885-896, 2013.

[51] R. Zhang, Z. Zheng, M. Wang, X. Shen and L. Xie, "*Equivalent Capacity in Carrier Aggregation-Based LTE-A Systems: A Probabilistic Analysis*", IEEE Transactions on Wireless Communications, vol. 13, no. 11, pp. 6444-6460, 2014.

[52] M. Tavanpour, J. Mikhali and G. Boudreau, "*DEVS based Modeling of Shared Segmented Upload in LTE-A Mobile Networks*", Springer, pp. 60-66, 2015.

[53] A. Bikos and N. Sklavos, "*LTE/SAE Security Issues on 4G Wireless Networks*", IEEE Security & Privacy, vol. 11, no. 2, pp. 55-62, 2013.

[54] N. Henda and K. Norrman, "*Formal Analysis of Security Procedures in LTE- A Feasibility Study*", Springer, pp. 341-361, 2014.

[55] L. Carlà, R. Fantacci, F. Gei, D. Marabissi and L. Micciullo, "*LTE enhancements for public safety and security communications to support group multimedia communications*", IEEE Network, vol. 30, no. 1, pp. 80-85, 2016.

[56] N. Henda, K. Norrman and K. Pfeffer, "*Formal Verification of the Security for dual connectivity in LTE*", IEEE, pp. 13-16, 2015.

[57] V. Kaul, V. Bharadi, P. Choudhari, D. Shah and S. Narayankhedkar, "*Security Enhancement for data transmission in 3G/4G*", IEEE, pp. 95-102, 2015.

[58] F. Oggier and M. Mihaljevic, "*An Information-Theoretic Security Evaluation of a Class of Randomized Encryption Schemes"*, IEEE Trans.Inform.Forensic Secur., vol. 9, no. 2, pp. 158-168, 2014.

[59] R. Jover, J. Lackey and A. Raghavan, "*Enhancing the security of LTE networks against jamming attacks*", EURASIP J Inform Secur, vol. 2014, no. 1, p. 7, 2014.

[60] B. Partov, D. Leith and R. Razavi, "*Utility Fair Optimization of Antenna Tilt Angles in LTE Networks*", IEEE/ACM Transactions on Netw..orking, vol. 23, no. 1, pp. 175-185, 2015.

[61] C. Hahn, H. Kwon, D. Kim, K. Kang and J. Hur, "*A Privacy threat in 4th Generation Mobile Telephony and its Countermeasure*", Springer, pp. 624-635, 2014.

[62] B. Fu, D. Staehle, G. Kunzmann, E. Steinbach and W. Kellerer, "*QoE-Based SVC Layer Dropping in LTE Networks Using Content- Aware Layer Priorities*", ACM Trans. Multimedia Comput. Commun. Appl., vol. 12, no. 1, pp. 1-23, 2015.

[63] A. Miyim, M. Ismail and R. Nordin, "*Vertical Handover Solutions Over LTE-Advanced Wireless Networks: An Overview*", Wireless Pers Commun, vol. 77, no. 4, pp. 3051-3079, 2014.

[64] E. Edward, "*A Novel Seamless Handover Scheme for WiMAX/LTE Heterogeneous Networks*", Arab J Sci Eng, vol. 41, no. 3, pp. 1129-1143, 2015.

[65] M. Park and Y. Joo, "*Efficient Handover Strategy for Inbound Mobility to LTE Small Cell*",Wireless Pers Commun, vol. 82, no. 3, pp. 1435-1447, 2015.

[66] H. Wang, S. Kao, C. Hsiao and F. Chang, "*A moving direction prediction-assisted handover scheme in LTE networks*", EURASIP J Wirel Commun Netw, vol. 2014, no. 1, p. 190, 2014.

[67] P. Sasdrich and T. Güneysu, "*Implementing Curve25519 for Side-Channel--Protected Elliptic Curve Cryptography*", ACM Trans. Reconfigurable Technol. Syst., vol. 9, no. 1, pp. 1-15, 2015.

[68] I. Grabska and K. Szczypiorski, "*Steganography in Long Term Evolution Systems*"", IEEE, pp. 92-98, 2014.

[69] I. Yoo, B. Kim and I. Park, "*Tail-Overlapped SISO Decoding for High-Throughput LTE-Advanced Turbo Decoders*", IEEE Trans. Circuits Syst. I, vol. 61, no. 9, pp. 2711-2720, 2014.

[70] T. Breddermann and P. Vary, "*Rate-Compatible Insertion Convolutional Turbo Codes: Analysis and Application to LTE*", IEEE Transactions on Wireless Communications, vol. 13, no. 3, pp. 1356-1366, 2014.

[71] H. Kim, D. Han, S. Hong and J. Ha, "*Message blinding method requiring no multiplicative inversion for RSA*", TECS, vol. 13, no. 4, pp. 1-10, 2014.

[72] Y. Huang, F. Leu, I. You, Y. Sun and C. Chu, "*A secure wireless communication system integrating RSA, Diffie–Hellman PKDS, intelligent protection-key chains and a Data Connection Core in a 4G environment*", J Supercomput, vol. 67, no. 3, pp. 635-652, 2013.

[73] Y. Huang, F. Leu, Y. Sun, C. Chu and C. Yang, "*A secure wireless communication system by integrating RSA and Diffie-Hellman PKDS in 4G environment and an intelligent protection- key chain with a data connection core*", IEEE, 2014.

[74] T. Mshvidobadze, "*Evolution Mobile Wireless Communication And LTE Networks*", IEEE, 2012.

[75] V. Pereira and T. Sousa, "*Evolution of Mobile Communication: from 1G to 4G",* IEEE, 2015.

[76] J. Ribadeneira-Ramirez, G. Martinez, D. Gomez-Barquero and N. Cardona, "*Interference Analysis Between Digital Terrestrial Television (DTT) and 4G LTE Mobile Networks in the Digital Dividend Bands*", IEEE Trans. on Broadcast., vol. 62, no. 1, pp. 24-34, 2016.

[77] A. El Essaili, Z. Wang, E. Steinbach and L. Zhou, "*QoE-Based Cross-Layer Optimization for Uplink Video Transmission*", ACM Trans. Multimedia Comput. Commun. Appl., vol. 12, no. 1, pp. 1-22, 2015.

[78] Y. Lin, R. Liou, Y. Sung and P.Cheng, "*Performance Evaluation of LTE eSRVCC with Limited Access Transfers*", IEEE Transactions on Wireless Communications, vol. 13, no. 5, pp. 2402-2411, 2014.

[79] Z. Rafea Ahmed, S. Subramaniam, Z. Ahmad Zukarnain and M. Othman, "*Best Minimum Summation Scheduler for Long Term Evolution*", Wireless Pers Commun, vol. 77, no. 3, pp. 2271-2289, 2014.

[80] H. Mohammed and P. Radcliffe, "*A packet scheduling scheme for 4G wireless access systems aiming to maximize revenue for the telecom carriers*", Telecommunication Systems, vol. 57, no. 4, pp. 347-366, 2013.

[81] H. Wang and S. Kao, "*Activity Selection-Based Single Carrier-Frequency Division Multiple Access Uplink Scheduling for Two-Tier LTE Networks*", Wireless Pers Commun, vol. 82, no. 1, pp. 625-642, 2014.

[82] S. Deb and P. Monogioudis, "*Learning-Based Uplink Interference Management in 4G LTE Cellular Systems*", IEEE/ACM Transactions on Networking, vol. 23, no. 2, pp. 398-411, 2015.

[83] J. Brown and J. Khan, "*A Predictive Resource Allocation Algorithm in the LTE Uplink for Event Based M2M Applications*", IEEE Transactions on Mobile Computing, vol. 14, no. 12, pp. 2433-2446, 2015.

[84] Q. Liu and C. Chen, "*Smart Downlink Scheduling for Multimedia Streaming Over LTE Networks With Hard Handoff*", IEEE Trans. Circuits Syst. Video Technol., vol. 25, no. 11, pp. 1815-1829, 2015.

[85] S. Niafar, Z. Huang and D. Tsang, "*An Optimal Standard-Compliant MIMO Scheduler for LTE Downlink*", IEEE Transactions on Wireless Communications, vol. 13, no. 5, pp. 2412-2421, 2014.

[86] Y. Yuan, Z. Zuo, Y. Guan, X. Chen, W. Luo, Q. Bi, P. Chen and X. She, "*LTE-Advanced coverage enhancements*", IEEE Commun. Mag., vol. 52, no. 10, pp. 153-159, 2014.

[87] M. Alam, D. Yang, J. Rodriguez and R. Abd-alhameed, "*Secure device-to-device communication in LTE-A*", IEEE Commun. Mag., vol. 52, no. 4, pp. 66-73, 2014.

[88] D. Dababneh, M. St-Hilaire and C. Makaya, "*Data and Control Plane Traffic Modelling for LTE Networks*", Mobile Networks and Applications, vol. 20, no. 4, pp. 449-458, 2015.

[89] A. Sharma, A. Trivedi and N. Roberts, "*Efficient Load Balancing using D2D Communication and Biasing in LTE-Advance Het- Nets*", ACM, 2015.

[90] H. Tang, Z. Ding and B. Levy, "*Enabling D2D Communications Through Neighbor Discovery in LTE Cellular Networks*", IEEE Transactions on Signal Processing, vol. 62, no. 19, pp. 5157-5170, 2014.

[91] J. Aviles, M. Toril and S. Luna-Ramirez, "*A femtocell location strategy for improving adaptive traffic sharing in heterogeneous LTE networks*", Springer, pp. 1-13, 2016.

[92] M. Shalaby, M. Shokair and N. Messiha, "*System Design and Performance Analysis of LTE Cognitive Femtocells*", Wireless Pers Commun, vol. 85, no. 4, pp. 2463-2483, 2015.

[93] K. Wang, X. Li, H. Ji and X. Du, "*Modeling and Optimizing the LTE Discontinuous Reception Mechanism under Self-Similar Traf.fic*", IEEE Trans. Veh. Technol., pp. 1-1, 2014.

[94] T. Maksymyuk, L. Han, X. Ge, H. Chen and M. Jo, "*Quasi-Quadrature Modulation Method for Power-Efficient Video Transmission Over LTE Networks*", IEEE Trans. Veh. Technol., vol. 63, no. 5, pp. 2083-2092, 2014.

[95] J. Poncela, G. Gómez, A. Hierrezuelo, F. Lopez-Martinez and M. Aamir, "*Quality Assessment in 3G/4G Wireless Networks*", Wireless Pers Commun, vol. 76, no. 3, pp. 363-377, 2014.

[96] J. Molina-Gil, P. Caballero-Gil and A. Fuster-Sabater, "*Analysis and implementation of the SNOW 3G Generator Used in 4G/LTE Systems*", Springer, pp. 499-507, 2016.

[97] N. Khan and M. Martini, "*Resource Allocation and Scheduling for Video Transmission over LTE/LTE-A Wireless Systems*", Springer, pp. 551-578, 2014.

[98] S. Kumar, E. Hamed, D. Katabi and L. Erran Li, *"LTE radio analytics made easy and accessible"*, ACM SIGCOMM Computer Communication Review, vol. 44, no. 4, pp. 211-222, 2014.

[99] L. Qi, S. Yameng, L. Fuchang and F. Bin, "*Research on services modeling in LTE networks*", China Communications, vol. 13, no. 2, pp. 109-120, 2016.

[100] A. Masaracchia, "*opportunistic traffic offloading mechanisms for mobile/4G Networks*",ACM, pp. 15-19, 2015.