RACH CONGESTION IN VEHICULAR NETWORKING

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ABSTRACT

Long term evolution (LTE) is replacing the 3G services slowly but steadily and become a preferred choice for data for human to human (H2H) services and now it is becoming preferred choice for voice also. In some developed countries the traditional 2G services gradually decommissioned from the service and getting replaced with LTE for all H2H services. LTE provided high downlink and uplink bandwidth capacity and is one of the technology like mobile ad hoc network (MANET) and vehicular ad hoc network (VANET) being used as the backbone communication infrastructure for vehicle networking applications. When Compared to VANET and MANET, LTE provides wide area of coverage and excellent infrastructure facilities for vehicle networking. This helps in transmitting the vehicle information to the operator and downloading certain information into the vehicle nodes (VNs) from the operators server. As per the ETSI publications the number of machine to machine communication (MTC) devices are expected to touch 50 billion by 2020 and this will surpass H2H communication. With growing congestion in the LTE network, accessing the network for any request from VN especially during peak hour is a big challenge because of the congestion in random access channel (RACH). In this paper we will analyse this RACH congestion problem with the data from the live network. Lot of algorithms are proposed for resolving the RACH congestion on the basis of simulation results so we would like to present some practical data from the live network to this issue to understand the extent RACH congestion issue in the real time scenario.

KEYWORDS

RACH; Congestion; LTE; Human to Human (H2H);Machine to Machine (M2M);Vehicle Nodes (VN); Mobile ad hoc network (MANET);Vehicular ad hoc network (VANET)

1. INTRODUCTION

Enabling wireless connectivity to the cars and making the transportation system intelligent has become a buzz word in lot of developed/developing countries. The Global car sales by 2020 is projected to be around 90 million units. The trend is going to go upwards in the subsequent years. As per the survey conducted by Bureau of Transport and Regional Economics in Australia[1], the projected travelling distance by people would be around 275 billion kilometres. So this raises another important point that people are going to spend lot of time in cars than at home and other place. So it become imperative that we must extend all the facilities of modern communication systems to the cars. So in this aspect vehicular communication is becoming more essential day by day. On the other hand the growth of communication systems has seen some tremendous growth in terms of technology and as well as with customer base. Moreand more people are migrating from GSM/3G to LTE because of high data rate. With the advent of LTE/LTE-A the data usage has surpassed the other traditional services like voice and text. In a recent study by Deloitte by 2016 LTE is forecast to carry more data traffic than 3G globally [2]. The imperative for carriers

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will be to build coverage and capacity as quickly and economically as possible. So when we carefully analyze this situation the extension of this communication facility inside the car environment and making our transportation system intelligent would be the ideal step forward.
In order to implement intelligent transportation system (ITS) IEEE has specified some standards like IEEE 802.11 p[1] which supports VANETs. This technology is very easy to deploy, cost effective and mature technology. But comes with some disadvantage like scalability issue, Quality of service (QoS) guarantees and it does not have proper end to end infrastructure for wide coverage. On the other hand LTE provides adequate infrastructure support and hence can guarantee QoS, it can provide wide coverage and the issue of blind spots (no coverage area zones) is minimized. But LTE comes with another disadvantage like network congestion because of growing customer base. So in this paper we will analyze the problem of congestion in LTE network which acts as an impediment to cater the ITS applications and service to the vehicles.

2. FUNDAMENTAL CONSIDERATION

The basic idea of 2G, 3G and 4G architecture design is to serve H2H communication. But with growing competition between the various mobile operators to capture the major chunk of the customer base the operators are forced to increase the investment in network expansion, QoS and low cost services and hence results in reduced average revenue per user (ARPU). This naturally brings down the capex and increases opex. So in order to increase the revenues the operators are looking for various avenues to make profits. One such avenue is providing latest communication services inside the VNs. The VNs can also be categorized under M2M or MTC devices. This service can increase the mobile operators' connection and revenue growth and as well as the most common go-to-market scenarios that apply to mobile operators in the M2M value add chain.

2.1. LTE network architecture

LTE, unlike its predecessor technologies like 2G and 3G, LTE is designed completely to provide seamless internet protocol connectivity between the user equipment (UE) and packet data network (PDN). While the term “LTE” includes the evolution of the universal mobile telecommunications system (UMTS) radio access through the evolved UTRAN (E-UTRAN), it is also accompanied by an evolution of the term “System Architecture Evolution” (SAE), which encompasses the evolved packet core (EPC) network. Together the LTE and SAE comprise the evolved packet system (EPS). EPS uses the EPS bearers to route the IP traffic from the gateway in the PDN to the UE. A bearer can be defined as an IP packet flow with a defined QoS between the gateway and the UE. The set up and release of bearers with respect to the applications are provided by the E-UTRAN and EPC together. EPS provides the user with IP connectivity to a PDN for internet accessing, and for running services such as Voice over IP (VoIP). An EPS bearer is typically associated with a QoS. Multiple bearers can be established for the user in order to provide multiple QoS streams or connectivity to different PDNs. For example, a user can be engaged in a voice (VoIP) call and can perform web browsing or FTP download at the same time. The necessary QoS for the voice call would be provided by the VoIP bearer, while for web browsing and FTP session the necessary QoS would be provided by the best-effort bearer. The LTE network architecture is designed in such a way to provide sufficient security protection for the network and privacy to the users against the fraudulent usage of the network.

At a high level, the LTE network comprises of the Core Network (CN) which is EPC and the access network E-UTRAN. While the CN is made up of many logical nodes, the access network is comprises of just one node, the evolved NodeB (eNB), which in turn connects to the UEs. Every network elements in the LTE architecture is interconnected by various interfaces which are standardised by the 3GPP in order to allow interoperability between different vendors. This gives the opportunity to the network operators to source different network elements from different vendors. Based on this the network operators have the freedom to choose between the vendors and they can construct their network with a single vendor or they can split choose the vendors for various network elements. depending on commercial considerations.

The CN (called as evolved packet core in SAE) is responsible for the overall control of the network and the establishment of the bearers various services. The main logical nodes of the EPC are:

• PDN Gateway (P-GW)
• Serving Gateway (S-GW)
• Mobility Management Entity (MME)

In addition to those above specified nodes, EPC also includes other logical nodes and functions such as the Home Subscriber Server (HSS) and the Policy Control and charging Rules Function (PCRF). Since the EPS only provides a bearer path of a certain QoS services, the control of multimedia applications such as VoIP is provided by the IP Multimedia Subsystem (IMS), which is considered to be outside the EPS itself.

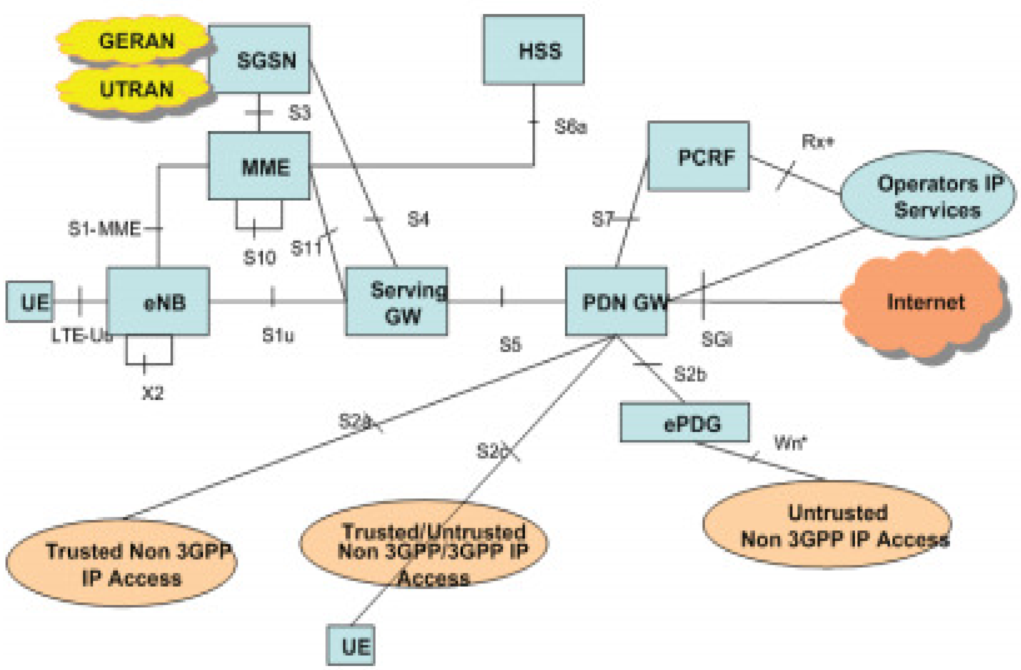

Figure 1. LTE Architecture

Table 1. LTE reference points.

PCRF	Responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW.
HSS	The Home Subscriber Server contains users' SAE subscription data such as the EPS-subscribed QoS profile and any access restrictions for roaming.
P-GW	The PDN Gateway is responsible for IP address allocation for the UE, as well as QoS enforcement and flow-based charging according to rules from the PCRF.
S-GW	All user IP packets are transferred through the Serving Gateway, which serves as the local mobility anchor for the data bearers when the UE moves between eNodeBs.
MME	The Mobility Management Entity (MME) is the control node that processes the signaling between the UE and the CN.

2.2. LTE infrastructure as Backbone in Vehicular Networking

There are several reasons why LTE is considered as one of the leading contender to provide backbone infrastructure for vehicular networking.

The first and foremost reason for this is adequate coverage of LTE network. As the subscriber base increases every day the operators are rapidly expanding the LTE network. This in turn provides good coverage for vehicle networking applications. The second reason, is the LTE provides good QoS in terms of data throughput in the downlink channel. So if a user of the vehicle nodes makes a request which amounts to some big bandwidth requirement then LTE can readily support it. Thirdly, LTE network provides a centralised architecture which can be used by the vehicle networking applications to reach the central content server to request or make fresh demand. The LTE air interface can support various access technologies like time-division duplexing (TDD), frequency- division duplexing (FDD), and half-duplex FDD schemes; it also provides channel bandwidth of (1.4–20 MHz). Concerning the access technology in LTE, orthogonal frequency-division multiple access (OFDMA) is used in the downlink and single-carrier frequency-division multiple access (SC-FDMA) in the uplink, both providing high flexibility in the frequency-domain scheduling. Usage of multiple-input multiple-output (MIMO) techniques in LTE would improve the spectral efficiency by a factor of 3 to 4 compared to other generation (2G/3G) systems even at very high speeds, making LTE very efficient in challenging and dynamic propagation environments like the vehicular one. eNodeB manages the radio resources centrally at every transmission time interval of 1ms duration and provides efficient QoS while increasing the channel utilization. Packet scheduler plays an important role in the eNodeB by selecting the traffic flow to serve the UEs based on the QoS requirements and services (as specified by the QoS class identifier, QCI), and further decides the suitable modulation and coding scheme based on feedback from the mobile terminals about the channel in the channel quality indicator (CQI). QCI refers to a set of packet forwarding treatments, for example, resource type (guaranteed or not guaranteed bit rate), priority, packet loss rate and delay budget. LTE also supports high-quality multicast broadcasting and multicasting services which is similar to 3G but it is evolved in LTE and termed as eMBMS in the core and in the radio access network. It offers the possibility of sending the data *only once to a set of users* registered to the offered service, instead of sending it to *every node separately*. The standardization of LTE-Advanced (LTEA) is ongoing in 3GPP (Rel. 11) as a major enhancement of LTE in terms of bit rate, capacity, and spectral efficiency, mainly through the support of advanced MIMO techniques, carrier aggregation, and relay nodes. With LTE-A still in an early stage, the focus of the related work reported in this article is on LTE.

Since LTE provides centralized architecture it cannot support Vehicle to vehicle (V2V) communications[3][4]. But there is also some disadvantage of LTE being used in this vehicular application. The first and foremost is, in cellular network the non active devices will be in idle mode in-order to save the network resources. So in-order to transmit the request to the central content server the VNs should be in active mode. The VNs should request for random access channel (RACH) to request for resources to transmit some data in uplink channel (PUSCH). But because of RACH overloading/congestion in the LTE network the VNs may experience collision in preamble ID and can face problems to receive random access response (RAR) from the eNB. The focus of this paper is to prove that in future with growing number of LTE subscribers and also equally increasing MTC devices the Rach congestion/overloading [5] is going to be a big bottleneck for these devices to attach to the network. Many people have published various algorithms for this RACH congestion issue on the basis of computer simulation results. But in this paper an attempt is made to analyse the RACH data from the real network which was collected for over the period of three months. This was supported by set simulations which was done to analyse the preamble ID collision and re-transmission issue.

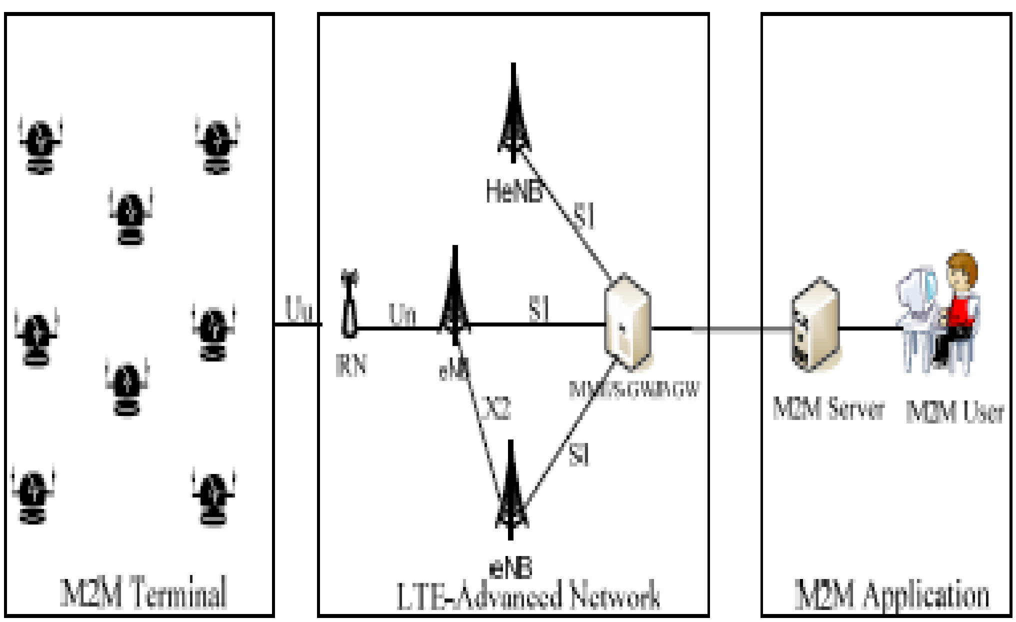

Figure 2. Vehicular networking architecutre (Anthony Lo et al.,)

3. Problem Statement

With ever increasing vehicle population and subsequent increase in road infrastructure to support it, the transportation scenarios has become complex day by day. The government agencies and infrastructure planners are working more seriously to plan for future traffic growth. For example a small incident in a road can cause huge traffic blocks and delays. So in this scenario the information regarding the roads needs to be published to the drivers so that they can be diverted to their destinations through other available alternative routes. Lot of techniques are employed to enable this to happen. One such technique is by using by LTE in vehicular networking. As per the ETSI publications[6] the number of MTC devices are expected to touch 50 billion by 2020 and this will surpass the H2H. With growing congestion in the LTE network, accessing the network for any request from vehicles (from idle mode to active mode) especially during peak hour is going to be a big challenge because of RACH congestion/overloading. In a LTE cell 64 preambles signatures are available in that some are used for contention based allocation and some are used for contention free allocation. So not all 64 preamble signatures are available for UE's or VNs to use to access the network this results in collision and re-transmission which clogs the network. This will have a serious impact in the freshness of the data received from the network.

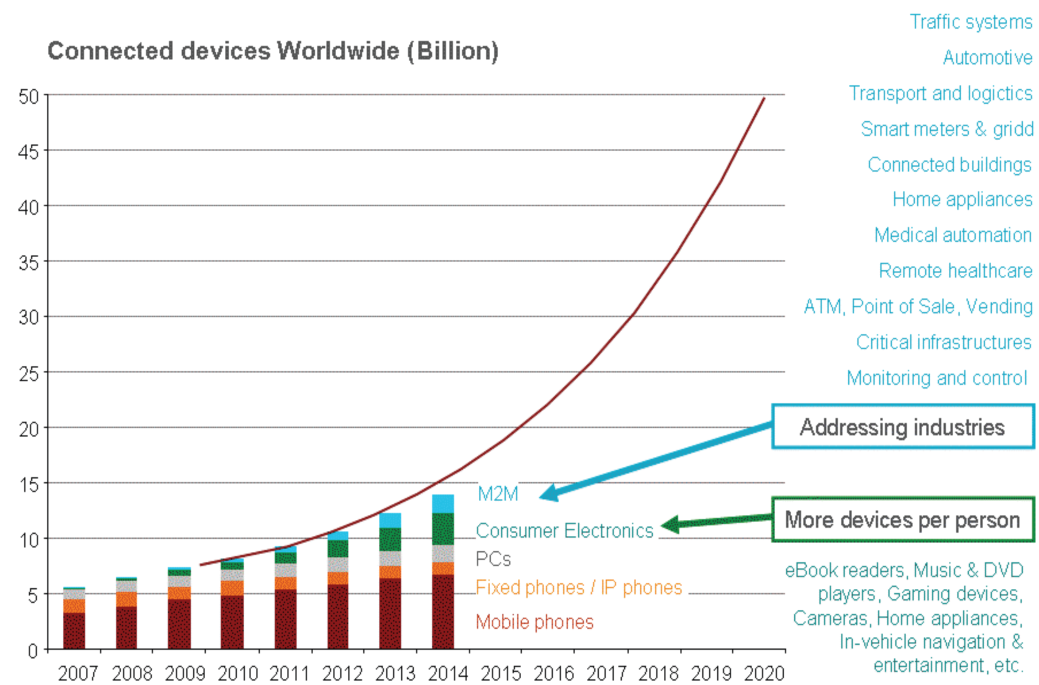

Figure 3. M2M devices service and forecast (Ericsson)

3.1. RACH process and Congestion - Simulation Results

The RACH procedure begins when VNs has something to transmit on the physical random access channel (PRACH). The process starts the message exchange between the VNs and eNB. This process has two different types of variants and they are contention based random access procedure and contention free random access procedure. The later part is used by the network to assign a preamble to the UE during the handover process and since the preamble IDs are handled by the network the congestion in this procedure is virtually non-existence. But the focus of this paper is contention based random access procedure. The VNs are usually in idle mode and they will not be in connect mode to the network. So when a request is being placed in the VNs they contact the eNB for resource allocation in uplink. As a result of this the VNs will receive resource to transmit the query in the uplink, initial timing advance value in the uplink and temporary C-RNTI.

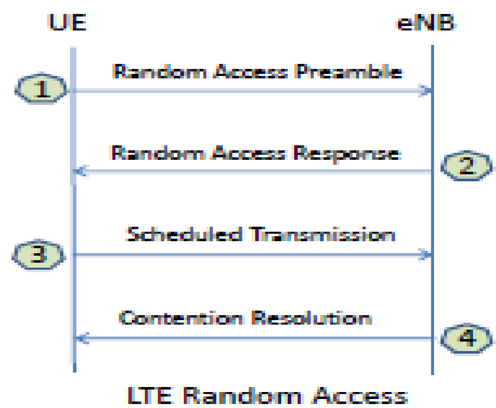

Figure 4. Random access procedure in LTE (Han-Chuan Hsieh et. al.,)

Then status of the VN will change to RRC_IDLE to RRC_CONNECTED when the VN wishes to access the network to submit a query. But it will not have a PUSCH resource in the uplink channel to send the request. So it triggers a random access procedure. The VNs reads the cells random access configuration from SIB2 and chooses a preamble sequence at random from the available ones (apart from the ones used by the system for the contention based scheme). It then transmit on the same resource blocks using the same preamble sequence. The base station sends the scheduling command in RAR and this will be followed with the schedule transmission by the VN to the eNB in this process the VNs identifies itself using either by S-TMSI or by random number. The eNB sends a acknowledgement using PHICH. The base station address the VN using C-RNTI which it allocated earlier. It follows the command with MAC control element called contention resolution identity.

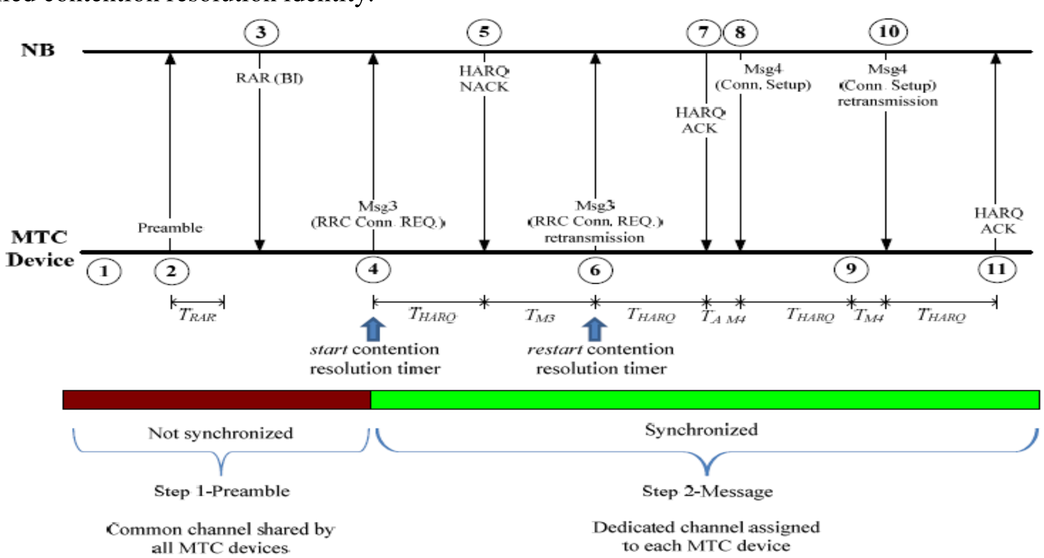

Figure 5. Random access procedure steps in VNs/MTC devices (Chia-hung wei et al.,)

3.2. RACH Overload/Congestion - Simulation Results

The overload control of uplink random-access channel (RACH) in radio access network (RAN) is one of the principle working items for 3GPP Long Term Evolution. The purpose of RAN overload control is to avoid RAN overload when mass VNs devices simultaneously contend for the RACH. From the perspective of the way that VNs/MTC traffic is generated, the RAN overload control schemes can be categorized into push-based and pull-based approaches. In the push-based approach, the VNs/MTC traffic is *pushed* from VNs/MTC devices to the network without any restriction until RAN overload is detected this scheme is not controlled by the network. In the pull-based approach, the VNs/MTC traffic is *pulled* by the network and thus, the network may properly control the VNs/MTC traffic load through paging and thus, prevents RAN overload. In another scheme called access class barring (ACB), separate RACH resources are allocated for VNs/MTC, in this scheme as dynamic allocation of RACH resource takes place, in VNs/MTC backoff scheme the VNs will be told to backoff if there is heavy congestion in the network and finally in slotted access scheme each VNs will be allocated a certain time slots and the VNs are allowed to transmit only during that time. In LTE, a downlink paging channel is defined to transmit the paging information to user equipment (UE), informing UEs on system information changes and emergency notifications. The network may transmit a paging message to activate a specific UE at the UE's paging occasion. The paging occasion of each UE is determined according to its UE identity (UE-ID). Current paging mechanism that was originally designed for H2H services can only page up to 16 devices with a single paging message, and only two paging occasions are available per 10 ms radio frame. Therefore, a BS must transmit multiple paging messages over a long period to activate a large number of VNs/MTC devices which substantially increases the load in the BS.

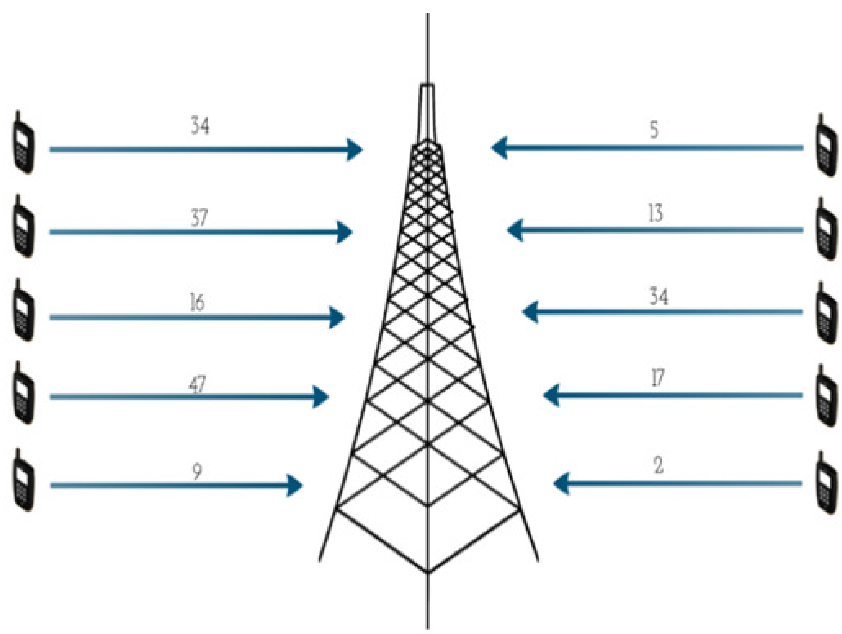

Figure 6. Random access procedure attempt with Preamble ID by UE/VNs

If VNs transmits same random number in different resource blocks there will not be any contention but if VNs transmit the same random number in the same resource blocks then there will be a contention. So the devices go for re-transmission automatically until it reaches the max retransmission attempts This scenarios likely to happen almost in all the network. The VNs and mobiles are going to use the same resources to access the network. As such the networks are busy because of the increasing customer base in LTE and as projected by ETSI many more MTC devices are going to join the same bandwagon in the future.

As per the simulation results developed using NS3[7] the probability of preamble collision increases as the number of mobile devices increases in the LTE cell.

Table 2. Nodes and collision percentage.

No of nodes attempting for Rach	Collision percentage
10	20
40	37.5
100	58
200	75

Table 3. Number of nodes and percentage of successful preamble id throughput.

No of nodes attempting for Rach	Percentage of Successful Preamble ID throughput
10	80
40	62.5
100	42
200	25

Table 4. Collision percentage and re-transmission attempts

Collision percentage	Retransmission attempts
20	3
37.5	10
58	25
75	50

The preamble collision and re-transmission simulation results shown in table 3 as the number of nodes increases the percentage of collision also increases and the re-transmission to make it through (table 4). This does not mean that the attempt is an failure. But the main disadvantage of increase in the number of re-transmission will increase the delay for the VNs to get the resource in the uplink channel to access the network for any request which will have adverse effect in the freshness of the data received and also will result in network wide congestion in the RACH.

3.2. Expected number of Unsuccessful users in accessing the RACH

The above simulation results confirms the percentage of collision and the number of re-transmission attempts to access the network. But that doesn't confirm that the attempts are failure ones. So in order to analyse the number of failures in accessing the uplink resource to access the network a practical approach was taken instead of simulation routes. The data that has been presented in figure 6 was the result of collection of counters for RACH failures for past three months from an live LTE network and in which more than a billion of RACH attempts where studied and from that RACH failure rate has been calculated. The below results shows only the RACH failures in the network. From this below figure we can attribute that 30% of the RACH attempts in the networks is failing and only 70% of the RACH attempts are successful. Through this analysis we want to confirm that LTE network is already getting clogged up without much use of VNs or MTC devices as of today and the situation will get worse if we start using them. At the same time a proper random access technique should be addressed to improve the situation as the current techniques has many shortcomings.

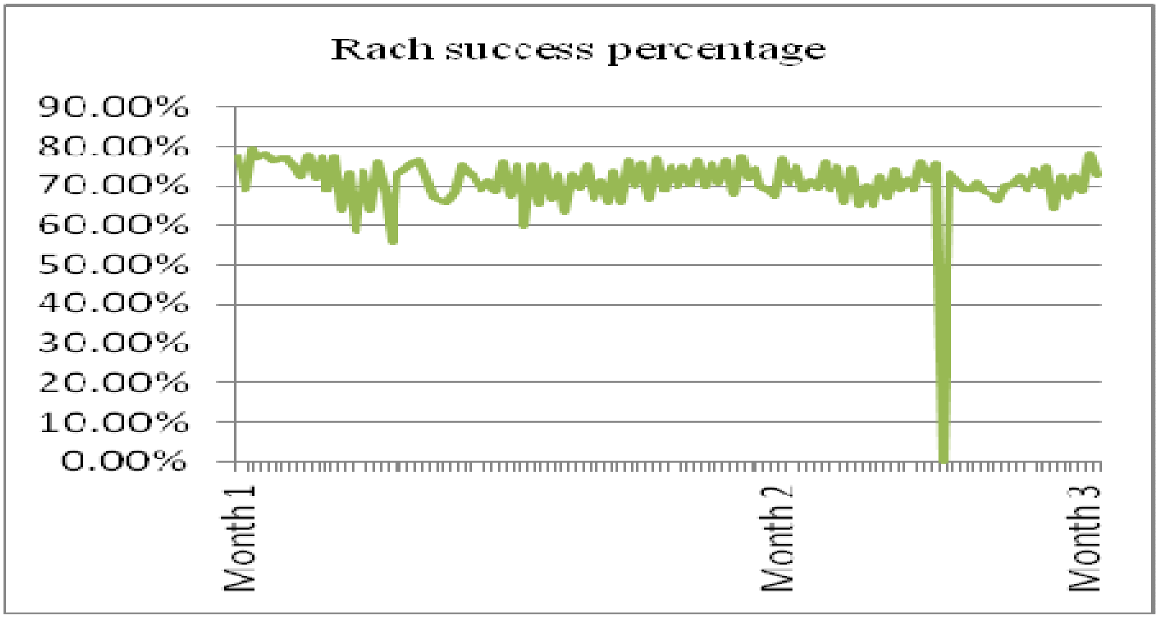

Figure 6. Rach failures results from Live network

4. CONCLUSION AND FUTURE WORK

As the multiscale framework to ITS modelling, network architecture design and traffic control of ITS is being developed with all the facilities of modern communication should be extended to vehicle environment. But in order to do so various technical challenges needs to addressed. One of the major challenge is to analyze the impact on the preamble collision, retransmission and RACH failures of the LTE network. In that attempt firstly, simulation was used to scale the preamble collition and re-transmissions was made and secondly, the data from the live network which was collected for over three months were used to scale the RACH failures. The results obtained will be used to design the new random access technique for M2M communication. So that the M2M services can co-reside along with the H2H services.

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