Impact of Machine-to-Machine (M2M) Communications on Disaster Management in Future Mobile Networks

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Abstract

Machine-to-Machine (M2M) communications is one of the main new areas of future mobile networks. There are many applications of M2M communications such as intelligent transport systems, smart metering and monitoring, and health care. These applications use a large number of mobile devices which can generate a huge amount of traffic along with different QoS requirements. Due to the mobility, most of the data has to be transmitted over wireless networks. Broadband transmission has to be performed through themobile communication systems which are widely available and deployed. Long Term Evolution (LTE) and LTE-advanced are the main promising broadband mobile technologies in current and future mobile communications.

Current traffic demand for regular mobile applications along with different service requirements is growing exponentially. Mobile technologies such as LTE and LTE-advanced which are based on Orthogonal Frequency Division Multiplexing (OFDM) technology provide promising capabilities to cater per such demands. Adding M2M communicationswith various Quality of Service (QoS) requirements to the regular mobile services has a significant impact on the overall system and end-to-end performance. The current wireless systems might run outofcapacity in the near future and the mobile traffic may not be transmitted efficiently. Enabling a large number of devices to communicate in the mobile system causes many challenges to the mobile operators in distributing the resources effectively among the mobile devices to meet their QoS requirements. Key issues such as prioritization and classification of a large number of devices, coordination of multiple providers to communicate with different devices, and provision of data and system security are challenging over the packetized paradigm. M2M communications generates both small and large sized messages to communicate among the devices. Small sized message communication is costly in terms of spectral efficiency in mobile communications. Some applications such as healthcare require stringent delay requirements whereas others need data integrity as the basic priority measures. For example, during disaster situations or any other emergency case, a large amount of traffic is generated towards base stations by not only the M2M devices but also the regular mobile users. In case of fire or flood, the building and vehicle alarms would simultaneously trigger resource requests. Currently, avoiding such congestion situations at the mobile networks is practically impossible for several mobile network operators. While using numerous machine-based devices in future mobile networks, similar situations can be expected to arise more frequently in day-to-day normal operations. When car-to-car communication is considered, congestion on a highway with multiple lanes occurs due to accidents. Many cars and mobile users in the region start simultaneous communication producing

a huge amount of traffic in the network. Therefore, future mobile communication needs to address these considerations and design mobile networks accordingly.

The LTE radio scheduler is one of the key entities which should be designed with great care to effectively manage and coordinate radio resources at the base stations. Designing an effective radio scheduler to optimize the scarce radio resources among the mobile devices, while guaranteeing QoS demands efficiently,is a great challenge in current research. In modern mobile communications, multiple- input and multiple-output (MIMO) antennas and beam forming technologies provide higher capacity over the radio interface. LTE systems use OFDM technology based scheduling both in the uplink and the downlink directions. Uplink scheduling scheme for LTE is the Single Carrier Frequency Division Multiple Access (SC-FDMA) and has much more limitations compared to the downlink from capacity, power and complexity point of view. Therefore within this framework, design challenges of uplink scheduling for future mobile communications are taken as the main consideration.

Keywords-component; SC-FDMA; uplink; scheduling; bandwidth; QoS

I. Introduction

The Machine-to-Machine (M2M) communications is a one of latest research areas which has achieved substantial endorsement. This technology aims at enabling machinesto communicate with each other without human intervention. The idea behind M2M communications is that the value of a machine increases when it is networked; whereas, a network attains more importance when it interconnects more machines [1].

The implementation areas of M2M communications include,but are not limited to, transportation, production, traffic systems, smart metering and monitoring, and healthcare [2]. The M2M communications are anticipated to have a strong impact on enhancing the standards of disaster management in all the implementation areas. The recognition of the nature, magnitude and site of disaster requires monitoring of several factors including temperature, pressure, humidity, light intensity and location. It is essential to communicate these readings to the emergency alarms of the disaster management authorities like police, fire brigade, ambulance etc. Based on the sensor readings, the authorities may execute properly managed remedial actions and take appropriate restorative measures to counteract unwanted situations. The counteractive measures taken by the authorities should also be facilitated by the communication infrastructure. This can bring extensive improvement to the standardsof disaster management. Hence, M2M communications can be vital for disaster management in the future.

Currently, M2M communications are based on contemporary wireless communication technologies like Global System for Mobile communications/General Packet Radio Service (GSM/GPRS), which are fulfilling the requirements of certain M2M applications sufficiently. The existing communication technologies offer low-cost deployment of M2M devices with roaming facilities and convenient deployment. However, it is expected that the number of devices based on M2M might undergo an exponential growth. According to [3], the number of connections for embedded mobile M2M applications was recorded as 87 million in 2009 worldwide, and is expected to reach the 428 million mark by 2014. Moreover, the future M2M applications would require broadband connections. The current wireless systems might run out-of-capacity in the near future and the M2M communications may not be facilitated proficiently.

Long Term Evolution (LTE) is the recent wireless communication standard of Third Generation Partnership Project (3GPP) developed to fulfill the data volume requirements of cellular mobile phones. The targets of LTE are increasing the peak user throughput, enhancing spectral efficiency and reducing latency for broadband services. The access network of LTE, the Evolved UMTS[1] Terrestrial Radio Access Network (E-UTRAN) consists of only two nodes, i.e., the eNodeB and User Equipment (UE). In the E-UTRAN, time and frequency resources are allocated by the Medium Access Control (MAC) layer scheduler of the eNodeB to the UEs. The scheduler considers the Quality of Service (QoS) requirements of different classes to dynamically allocate resources for downlink and uplink transmission of regular LTE traffic.

LTE is expected to be the future technology for providing M2M services. On one hand, the M2M applications are expected to offer a diverse range of services, including narrowband applications transmitting data infrequently. On the other hand, LTE is primarily developed for broadband data services. With narrowband applications, LTE cannot achieve spectrum and cost efficiency. Therefore, it is highly imperative that the architecture of LTE has to be redesigned in order to conform to M2M communications requirements. In a similar manner, the techniques for resource allocation to regular and M2M users of various QoS classes by LTE network have to be adapted accordingly.

II. PROBLEM DEFINITION

The probing questions that M2M communications pose are related to the distinctive characteristics of M2M messages. The most challenging issue is the expectedly large number of M2M messages. It is estimated that a large number of devices will be deployed in future for M2M communications. The disaster managementcould be supported by M2M devices deployed in various locations, transport vehicles, business centers and residential areas. It requires that the mobile network standards committees revise the networking designs for efficient support of these devices. The other major concern is the varying size of the M2M messages. The size of a M2M messages could be just a few bits as in case of a simple temperature reading. Likewise, messages of the order of mega bytes could also be transmitted as in case of a video monitoring device. The smallest resource unit allocable today in the LTE system to a User Equipment (UE) or device is the Physical Resource Block (PRB). Under favorable channel conditions, a PRB is able to transmit several kilo bytes of data. If one PRB is allocated to a single M2M device, the spectral efficiency would decline drastically. Synchronous transmission of messages is also an issue and can severely degrade the networks performance and block resources for other users. Such a situation can arise in cases of emergencies, such as fire, flood etc. For example, in case of fire in a warehouse, the building and vehicle alarms would simultaneously trigger resource requests. The issue of fulfilling the varying QoS requirements (regarding delay, throughput and packet loss rate) of different types of M2M messages is a challengingproblem that has to be addressed. Due to the diversity of M2M applications and QoS requirements, the complexity level of the scheduling algorithms is expected to be very high. Designing efficient algorithms with low complexity could be a painstaking task. Moreover, the LTE uplink constraints of PRB contiguity and Power Control (PC) make scheduling design even more complicated. All these challenges to instigate M2M communications and support disaster management with LTE networks should be addressed in such a manner that regular LTE services suffer minimumhindrance.

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[1]Universal Mobile Telecommunications System

III. STATE-OF-THE-ART

Considerable amount of research work is available on LTE downlink packet scheduling algorithms in literature as in [4,5,6]etc. LTE uplink scheduling has been addressed recently in literature but most of the work has been done by ignoring key LTE uplink features. In [7,8], the PRB contiguity constraint has been neglected, making the algorithm unfeasible for wireless SC-FDMA systems. The authors in [9,10,11] have dealt with PRB contiguity constraint; however, the QoS differentiation feature has not beenconsidered. Algorithm proposed in [12] introduces search-tree for resource allocation with fixed size and contiguous bandwidth allocation but the bandwidth flexibility feature of LTE uplink SC-FDMA has not beenexploited. Adaptive transmission bandwidth algorithms in [10,11] provides better throughput performance but the issue of QoS provision has not been attended. Algorithms based on QoS provision to single-bearer users are proposed in [13,14].The fulfillment of QoS requirements of multi-bearer users in uplink has seldom been discussed in literature. In fact, according to our knowledge, no research is available on multi-bearer uplink user scheduling to date.In algorithms for single-bearer UEs, the resource requests can be treated independently of each other and PRBs can be allocated from any portion of the bandwidth. If the multi-bearer UEs are present in the system, the resource requests having different QoS requirements within a single UE cannot be treated independently and the PRBs allocated to these requests should be contiguous. We have introduced and analyzed the performance of the Bandwidth and QoS Aware (BQA) LTE uplink scheduler in [15,16,17]. The BQA scheduler has been designed to fulfill the QoS requirements of various traffic classes for single and multi-bearer users in LTE uplink. The resources are allocated to users according to their channel conditions, buffer size and fairness criteria while considering the uplink constraints of contiguity and PC. In [15], the performance of BQA scheduler is analyzed with respect to delay sensitive traffic. In [16], the performance of BQA scheduler is compared with other contemporary schedulers. The performance of BQA scheduler in heterogeneous traffic environment is evaluated in [17].

Literature regarding scheduling in M2M communications is quite limited.Available work on the topic cover some degree of M2M aspects but still, the research is in embryonic phase. The author of [1] predicted steady growth in the M2M industry and highlighted the challenges of security, interconnectivity and employee training faced by the technology. In [18], the connection initiation problems in M2M communications on General Packet Radio Service (GPRS) and UMTS with possible solutions are discussed. In [19], the authors have proposed a framework to integrate mobile video service into home video service using M2M technology and benefit from the mobility and quality features of both services respectively.In [20], proposals regarding M2M architecture are presented to minimize complexity, reduce cost and enhance transmission efficiency. In [21], the diversity of the nature of the M2M messages is discussed and modifications in the PHY and MAC layer of LTE-A protocol stack are proposed. In [22], two simple LTE uplink scheduling algorithms are proposed and their performance is compared with other basic schedulers for M2M communications.Literature survey reveals the novelty of the topic.

IV. LTE Uplink Scheduler

LTE uplink scheduling algorithms are designed to characterize SC-FDMA features. The BQA scheduler evaluated in [15,16,17] has been designed to guarantee the QoS demands of the uplink traffic by considering the user channel conditions, user buffer size, fairness and the uplink constraints of PRB contiguity and PC. It has been shown to achieve good results for regular LTE traffic of voice, video, web browsing and file transfer.In order to overcome the challenges of M2M communications, as discussed above, it is eminent that the architecture and resource allocation techniques of LTE have to be revised. As mentioned earlier, LTE system has been developed to facilitate high data rate traffic. The utilization of current LTE system for low data rate traffic would adversely affect the spectrum efficiency.

The BQA scheduler is decoupled into time and frequency domain schedulers. The time domain packet scheduler (TDPS) allocates time resources to high priority users. TDPS selects a candidate list among the active users. The candidate users are considered for allocation of frequency resources in the frequency domain packet scheduler (FDPS). The TDPS candidate selection is based on TDPS metric values of the users generated by 'weighted Proportional Fair' (wPF) algorithm. The user metric value considersthe QoS weight and the channel conditions of UEs along with fairness. The QoS weight of a UE depends on throughput and delay requirements of its radio bearers. The TDPS metric value for UE i is formulated as:

$$\Lambda_i(t) = \frac{R_{inst,i}(t,n_i)}{R_{avg,i}} \sum_k W_{i,k}(t) \tag{1}$$

Where $\Lambda_i(t)$ is the TDPS metric value for UE i, $R_{inst,i}(t,n_i)$ is the instantaneously achievable throughput of UE i having maximum allowed number of PRBs n_i (set according to PC), $R_{avg,i}(t)$ is the average throughput of UE i at time t determined by using Exponential Moving Average (EMA) time window of 1s, $W_{i,k}(t)$ is the dynamic QoS weight of the bearer k of UE i at time t and expressed as:

$$W_{i,k}(t) = \frac{R_{\min,k}}{R_{avg.i.k}(t)} \cdot \frac{\tau_{i,k}(t)}{\tau_{\max,k}} \cdot \rho_k(t) \tag{2}$$

Where, $R_{\min,k}$ is the bit rate budget (target data rate) and $\tau_{\max,k}$ is the end-to-end delay budget (target delay) of QoS class k, $R_{avg\,i\,k}(t)$ is the average throughput and $\tau_{i,k}(t)$ is the average delay of bearer k of UE i, $\rho_k(t)$ is a variable with value set to 10 if $\tau_{i,k}(t)$ is above the threshold value of bearer k at time t, otherwise equal to 1. For various QoS classes, a list of bit rate budget, packet delay budget and delay threshold values is given in TABLE I. Bit rate budget for QoS classes is defined according to their traffic models. These values can be tuned to modify the behavior of the scheduler.

In FDPS, a certain number of high priority UEs are selected for allocation of frequency resources within the TTI. The bandwidth is divided into portions called Resource Chunks (RCs) as inFigure 1. The RCs are allocated to the chosen UEs based on FDPS metric values for each RC of each UE. The FDPS metric values are generated with 'Proportional Fair Scheduled QoS-aware' (PFSchedQ) algorithm and expressed as:

$$\lambda_{i,c}(t) = \frac{R_{inst,i,c}(t)}{R_{sch,avg,i}(t)} \cdot \sum_{k} W_{i,k}(t) \tag{3}$$

Where $\lambda_{i,c}(t)$ is the FDPS metric value for PRBc of UE i, $R_{inst,i,c}(t)$ is the instantaneously achievable throughput for PRB c of UE i, $R_{sch,avg,i}(t)$ is the average throughput of UE i over only those TTIs where i successfully enters the FDPS.

TABLE I: Bit Rate Budget, Delay Budget and Delay Threshold

Traffic Type	Bit rate budget (kbps)	Packet end-to-end delay budget (ms)	Packet delay threshold (ms)
VoIP	55	0.1	0.02
Video	132	0.3	0.1
HTTP	120	0.3	--
FTP	10	0.3	--

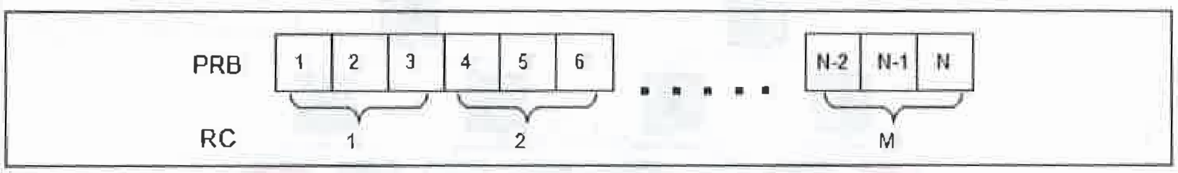


Figure 1: Chunk size 3 of M RCs and bandwidth of N PRBs

The allocation of RCs is achieved by the 'Fixed Size Chunk and Flexible Bandwidth' (FSCFB) algorithm. The FSCFB allocates RCs according to the RC combination yielding the best accumulative FDPS metric value; i.e. best sum of RC metric values (RC metric value is the sum of PRB metric values within an RC). The combinations not following contiguity, buffer size, and maximum allowed RCs constraints are discarded. The algorithm steps are summarized as follows:

1) Make a UE-RC table as inFigure 2. Each table element would be the RC metric value of the UE, i.e. the sum of PRB metric values within that RC.

2) Make all possible combinations of UE-RC allocation using search-tree algorithm (explained below) while respecting the contiguity, buffer size and maximum allowed bandwidth constraints; determine the resulting global metric value for each combination as in Figure 3.

3) Choose the combination with best global metric value.

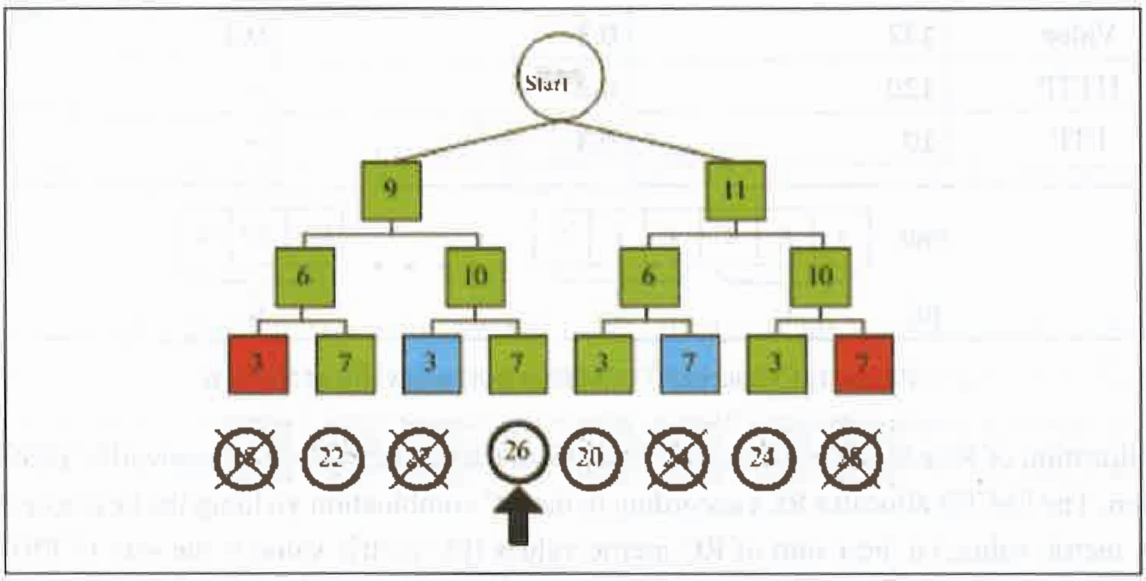
4) Obtain the desired resource allocation from best combination.

Step 2 is based on a search-tree based resource allocation algorithm termed as 'unique Depth-First Search' (uDFS) algorithm with contiguity, buffer size and maximum allowed bandwidth constraints. The uDFS checks all possible combinations of RC allocation and discards the combinations which do not follow the constraints; further depth of nodes breaching the constraints is not explored. An example of uDFS tree is given in Figure 3. It is assumed that at most, 2 RCs can be allocated to a UE. Blue nodes breach contiguity constraint and red nodes breach maximum PRBs constraint.

If the multi-bearer users acquire RCs, the allocated PRBs are further subdivided among the user bearers at the UE. The user bearers havetheir own QoS requirements such as delay budget, rate budget and delay threshold. The user bearers require sufficient resources to ensure QoS provision and avoid bearer starvation. In this research, the bearers get "weighted service", i.e. a bearer is served according to its QoS weight $W_{i,k}(t)$. If a bearer which reaches its packet delay threshold, itis given strict priority and available resources are allocated to it before other bearers are served.

	RC_0	RC_1	RC_2
UE_0	9	6	3
UE_1	11	10	7

Figure 2: A sample UE-RC table for two UEs and three RCs



A. *Scheduling for M2M Communications*

The commonly perceptible approach to tackle M2M communications related concerns would be to extend the network and deploy supplementary hardware. However, this is not an attractive way of problem solving because purchasing hardware to increase network capacity is costly and resolves the issue only temporarily. Efficient methods to support the increasing number and types of M2M devices to support M2M communications using LTE networks have to be developed. The approaches and methodologies proposed in this section are expected to effectively deal with the issues mentioned in section 2.

In this section, the foreseeable solutions are described and elucidated. The prevailing regular LTE QoS classes are not sufficient to represent the collective regular and M2M traffic. The resource scheduling can be made simpler if the QoS classes of regular and M2M traffic are combined and categorized within a common framework. A new categorization of regular and M2M classes is presented in [23] and illustrated inTABLE II.

TABLE II: Regular and M2M QoS Class Categorization

Class No.	Requirements			Regular class	M2M class
	Delay	Accuracy	Priority		
1	high	high	high		emergency alerting
2	high	low	high	conversational voice	
3	high	low	low	video	mobile streaming
4	high	high	low	browsing	mobile point-of-sale
5	low	high	low	file transfer	smart metering
6	low	low	low		regular monitoring

To reduce the complexity of the scheduling algorithms, the scheduling can be performed for each QoS class separately using simple scheduling algorithms instead of scheduling all the classes together with complex algorithms. This idea can be implemented by designing a resource estimator (Figure 4), which can allocate resources to different QoS classes based on current and previous buffer status. The resource estimator would make decision by considering the knowledge of previous resource allocations to QoS classes. Such a scheduling scheme can be highly efficient for downlink scheduling, where the signal is transmitted by the eNodeB to the regular and M2M devices. It would be possible to serve the M2M traffic efficiently according QoS requirements without significantly hampering the conventional mobile phone traffic.

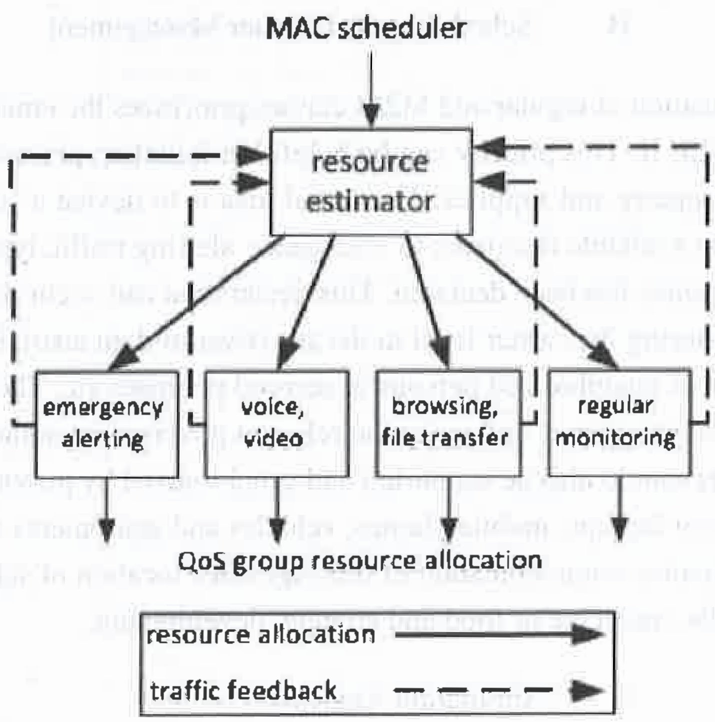


Figure 4: Resource estimator block diagram

In case of uplink scheduling, this scheme may not be practicable because of the constraints of the SC-FDMA based uplink transmission schemes in LTE. Uplink resources should be allocated in such a manner that the PRBs allocated to single device are contiguous to each other. If the devices have only a single class of traffic data to transmit, the resource estimation can be a useful approach. But in case of devices transmitting multiple traffic-type data, this approach cannot be utilized. Therefore, for uplink scheduling, instead of QoS class grouping, device based grouping can be exploited. The resource estimator would be making allocations of resources to user groups instead of QoS classes. The sensors, cameras and other M2M devices monitoring the goods, as well as the conventional mobile users would form groups. Each group of devices would be striving to acquire network resources.

A practical approach to enhance spectral efficiency is to reduce the size of the smallest downlink and uplink resource allocation unit from PRB to subcarrier. Instead of allocating PRBs, the devices might be able to obtain subcarriers for transmission. This would significantly reduce the overhead messaging and enhance PRB utilization. The resources can be efficiently utilized if several devices can share a single PRB and avoid bandwidth wastage.

Another similar interesting area to explore is to determine the feasibility of employing Code Division Multiple Access (CDMA) scheme within one or several PRBs. Generally, CDMA is a spread-spectrum technology and requires broadband for operation. In M2M communications, small sized messages can reduce the system throughput drastically if each message is allocated a PRB or an RC. Spectral efficiency could be enhanced if the small sized messages are combined together and multicasted to the receivers. Each receiver should be able to acquire its share from message combined with CDMA technique. The CDMA over PRBs can be an interesting topic to investigate. In case the solution is feasible, the PRB utilization can increase manifolds. This approach could be another avenue for efficient bandwidth utilization to enhance M2M communications with the LTE network.

B. Scheduling forDisaster Management

The QoS class categorization of regular and M2M classes prioritizes the emergency alerting type of traffic as given in TABLE II. This priority can be helpful in initiating prompt remedial actions and avoiding loss of life, property and supplies. The initial idea is to device a simple scheduling strategy by allocating all the available resources to emergency alerting traffic type, once the network is informed that the emergency has been declared. This declaration can occur due the signals from the sensors which are monitoring fire, water level in the sea (river or dam also), blood pressure or heart beat of a patient, access of unauthorized persons in secured premises etc. The network should make decision on the nature of emergency and make the relevant government authority aware of the situation. The rescue efforts should also be supported and synchronized by providing radio resources to the rescue teams and their laptops, mobile phones, vehicles and equipments with high priority. The rescue process might involve communication of messages like location of staff members, availability of rescue material like medicine or food and strategy development.

V. Simulation Analysis

The OPNET Modeler is used to perform the simulation analysis of the BQA scheduler for regular LTE traffic in [16]. The QoS and the throughput performance of the BQA scheduler is compared with the performance of other contemporary TDPS schedulers which are commonly used. These schedulers are the Blind Equal Throughput (BET), the Maximum Throughput (MT) and the Proportional Fair (PF). In FDPS, the PFSched scheduler is utilized by all the TDPS schedulers and therefore, the resource allocation algorithmi.e. FSCFB algorithm is also shared by the schedulers. The BQA scheduler serves the bearers of multi-bearer users according to QoS weights, whereas the otherschedulers serve the bearers by giving strict priority to GBR bearers. The simulation parameters used are given in TABLE III. Simulations are performed for two different types of users, i.e. the single and multi-bearer users. The performance of the schedulers is compared in terms of cell throughput and average traffic delays of various classes. In order to establish a throughput goal, the cell throughput of MT scheduler with 8 FTP single bearer users in the cell of approximately 10Mbps is set as the target cell throughput. The difference between the target and achieved throughput is defined as the evaluation criteria for scheduler throughput performance. The goal for each scheduler is to minimize the throughput difference along with traffic delays. These results are plotted with spider web charts. The schedulers strive to minimize the size of their respective webs.

TABLE III: Main Simulation Parameters

Parameter	**Setting**
Cell Layout	3 Cells, 1 eNodeB
System Bandwidth	5 MHz (~25 PRBs)
Frequency reuse factor	1
Cell radius	375m
UE velocity	120kmph
Max UE power	23dBm
Path loss	$128.1+37.6\log_{10}(R)$, R in km
Slow fading	Log-normal shadowing, 8dB standard deviation, correlation 1
Fast fading	Jakes-like method [24]
Mobility Model	Random Way Point (RWP)
Power Control	FPC, $\alpha = 0.6$, $P_0 = -58$dBm
Traffic environment	Loaded
Max FDPS UEs	5
RC size	5
VoIP traffic model	
Silence/ talk spurt length	Exponential(3) sec
Encoder scheme	GSM EFR
Video traffic model	
Frame size	1200 bytes
Frame inter-arrival time	75ms
HTTP traffic model	
Page size	100Kbytes
Page inter-arrival time	12 sec
FTP traffic model	
File size	20Mbytes
File inter-request time	Uniform distribution, min 80s, max 100s

A. Single-Bearer Scenarios

In the single-bearer scenarios, the BQA scheduler and the reference schedulers (BET, MT and PF) are compared with 8 FTP UEs in the initial scenario. The traffic is modified for successive scenarios by adding 2 VoIP UEs and 2 video UEs step-wise. In a nutshell, the simulations are performed for 8 FTP UEs with 2, 6 and 10 VoIP/video UEs and the comparison of schedulers is illustrated using spider web diagrams. The graphs depict the average cell throughput, VoIP end-to-end delay, video end-to-end delay and FTP response time results for the BQA scheduler and other reference schedulers.

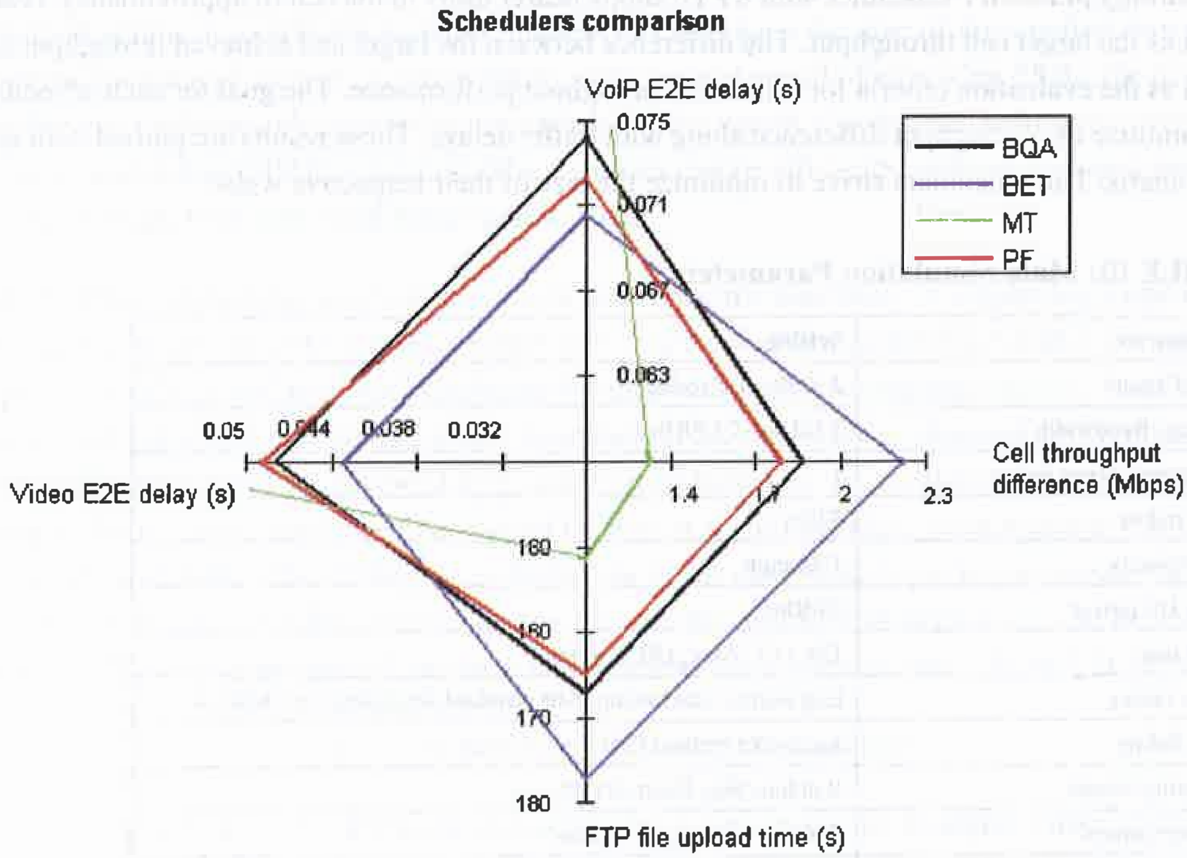


Figure 5: 2 VoIP and 2 video users

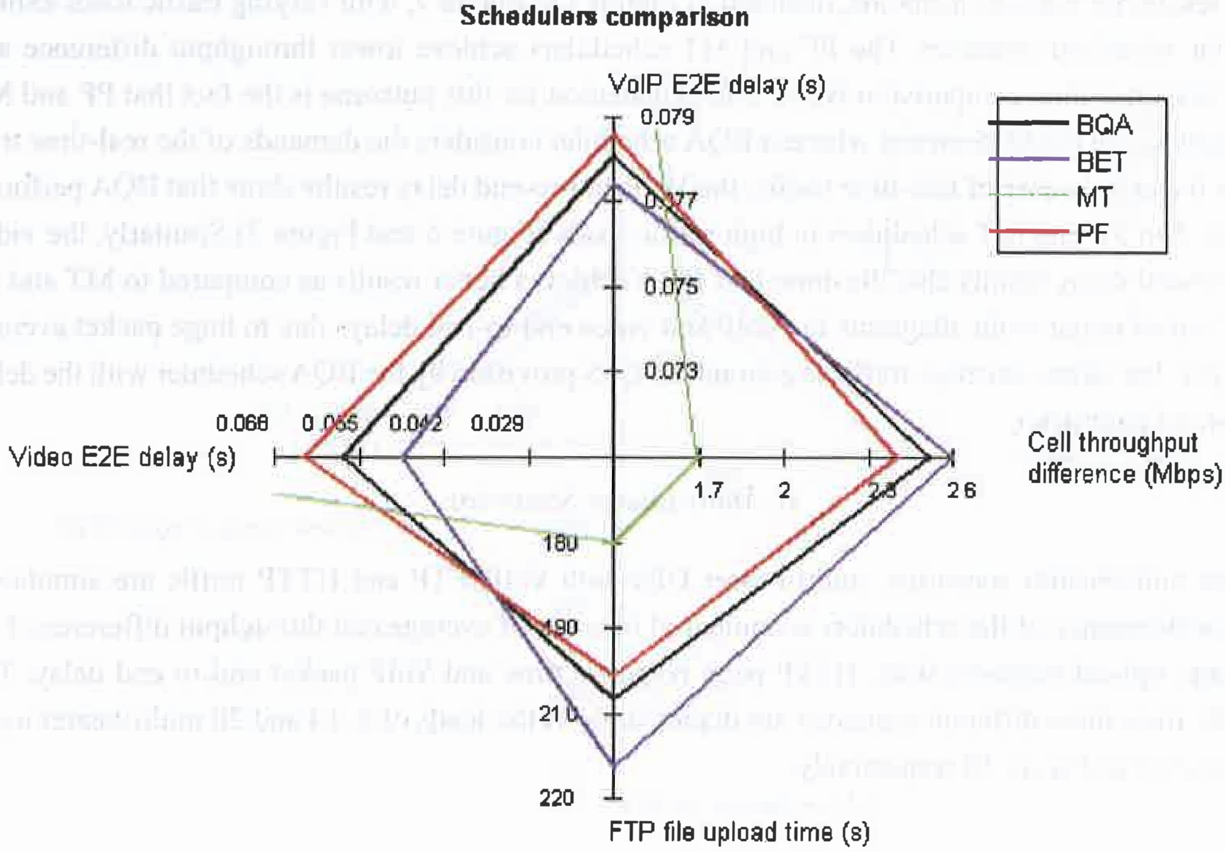


Figure 6: 6 VoIP and 6 video users

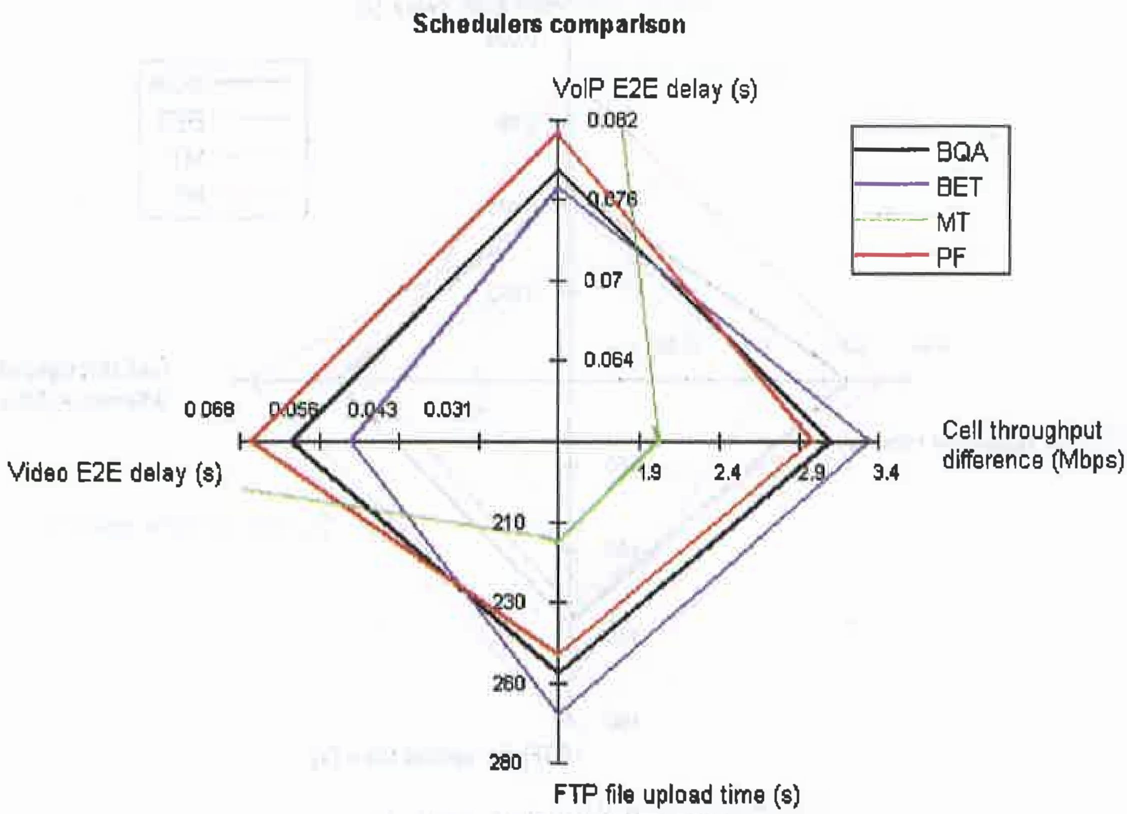


Figure 7: 10 VoIP and 10 video users

The results for various scenarios, depicted in Figure 5 to Figure 7, with varying traffic loads exhibit similar scheduler behavior. The PF and MT schedulers achieve lower throughput difference and FTP response time compared to BQA. The explanation for this outcome is the fact that PF and MT schedulers are not QoS aware, whereas BQA scheduler considers the demands of the real-time traffic in the cell. In case of real-time traffic, the VoIP end-to-end delay results show that BQA performs better than PF and MT schedulers in high traffic loads (Figure 6 and Figure 7).Similarly, the video end-to-end delay results also illustrate that BQA achieves better results as compared to MT and PF (MT out of range in the diagrams for VoIP and video end-to-end delays due to huge packet average delays). The delay sensitive traffic is guaranteed QoS provision by the BQA scheduler with the delay threshold parameter.

B. Multi-Bearer Scenarios

In the multi-bearer scenarios, multi-bearer UEs with VoIP, FTP and HTTP traffic are simulated. The performance of the schedulers is compared in terms of average cell throughput difference, FTP average upload response time, HTTP page response time and VoIP packet end-to-end delay. The results from three different scenarios are depicted for traffic loads of 8, 14 and 20 multi-bearer users in Figure 8 to Figure 10 respectively.

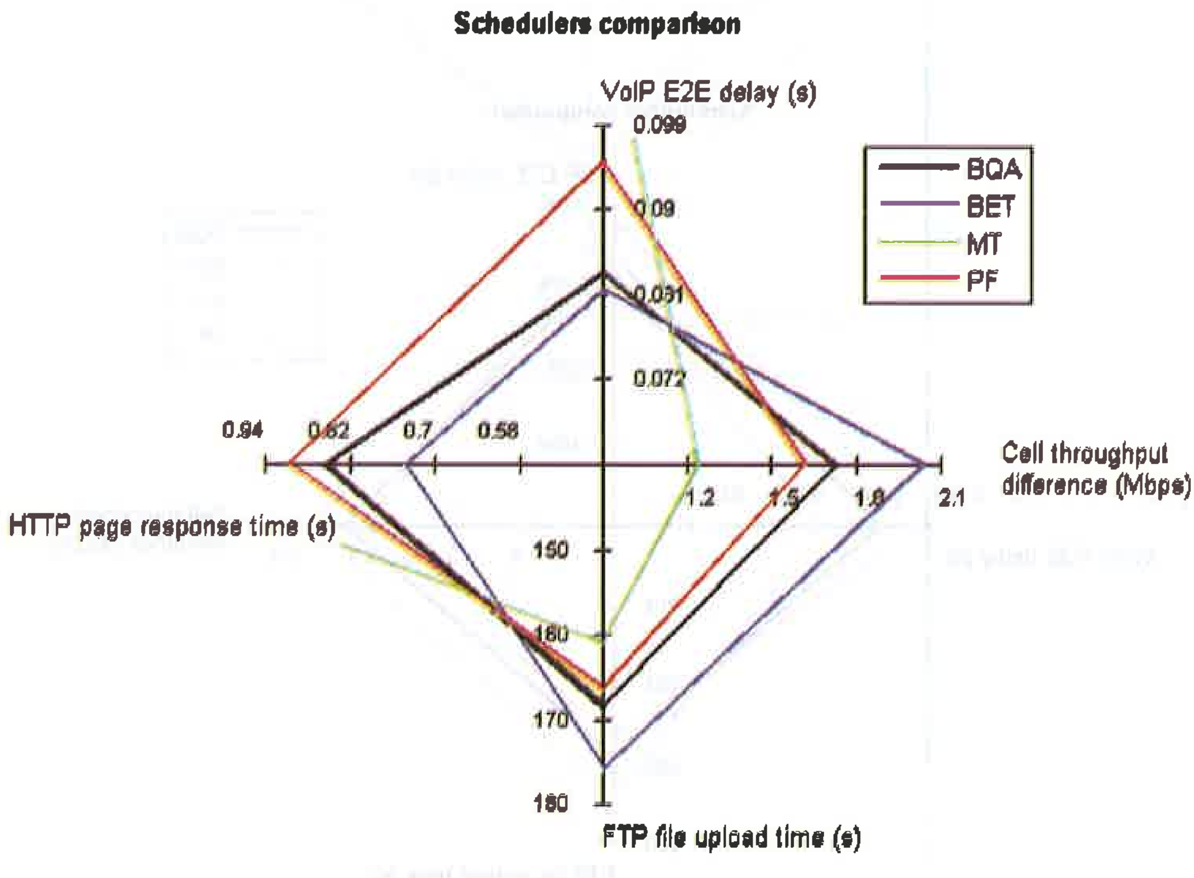


Figure 8: 8 multi-bearer users

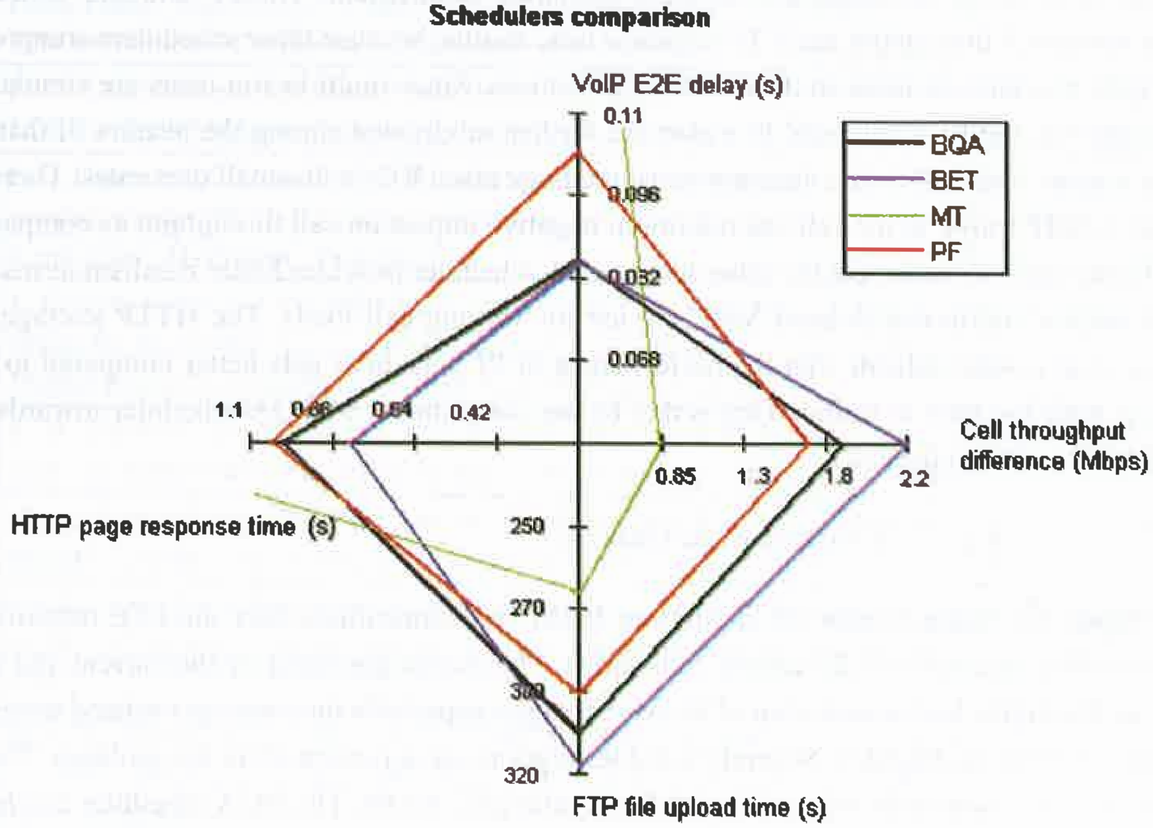


Figure 9: 14 multi-bearer users

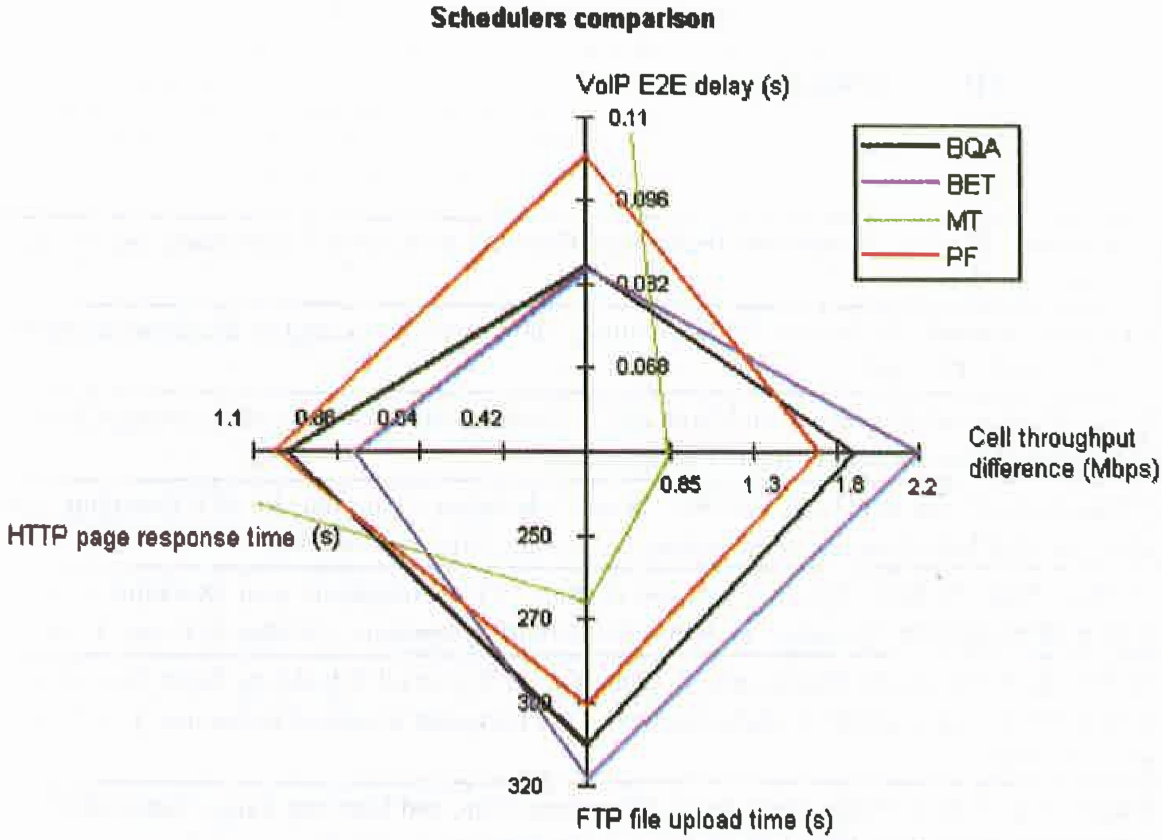


Figure 10: 20 multi-bearer users

The general behavior of schedulers in these scenarios isconsistent. The PF and MT schedulers achieve better cell throughput and FTP response time results, because these schedulers compromise on the QoS provision in order to achieve their objectives. Since multi-bearer users are simulated in these scenarios, the RCs allocated to a user are further subdivided among the bearers of that user. For this reason, the VoIP traffic does not consume large sized RCs with small data rates. Therefore, increase in VoIP traffic in the cell has minimum negative impact on cell throughput as compared to single-bearer user scenario. On the other hand, BQA scheduler provides better resultsin terms ofthe average packet end-to-end delayof VoIP service for varying cell loads. The HTTP average page response time results indicate that the performance of PF scheduler gets better compared to BQA scheduler with increase in traffic. This is due to the commitment of BQA scheduler towards high priority VoIP traffic in the cell.

VI. Conclusion and Outlook

In this paper, the research issue of facilitating M2M communications over the LTE network was discussedwith a mention of LTE uplink constraints. The challenges faced by the current and future mobile technologies for transmission of M2M messages, especially the messages related to disaster management, were highlighted. Several probable solutions were presented for the problem. The performance of BQA scheduler was evaluated for regular LTE traffic. The BQA scheduler can handle regular LTE traffic quite efficiently, however, still requires enhancements to be able to schedule M2M traffic efficiently. Furthermore, the scheduler capability of managing disaster and emergency situations is an interesting prospect for future investigations.

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