Performance Analysis of an Enhanced Delay Sensitive LTE Uplink Scheduler for M2M Traffic

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***Abstract*—The Long Term Evolution (LTE) standard is one of the most promising wireless access technologies for Machine to Machine (M2M) communications because of its high data rates, low latency and economies of scale. M2M communications typically involves a large number of autonomous devices sending traffic in a coordinated manner (and possibly even simultaneously), therefore creating an uplink-heavy trend which needs an efficient radio resource management scheme. The conventional scheduling algorithms and performance metrics are not suitable for M2M systems because of the different characteristics and service requirements of M2M traffic. In this paper, we analyze the performance of an enhanced delay sensitive uplink scheduler in context of LTE TDD configurations 0 and 1 for delay sensitive event based M2M traffic. We show that unlike an ordinary equal capacity fair scheduler, our proposed delay sensitive scheduler can make utmost use of the maximally uplink-biased TDD configuration 0, attaining higher capacity and maximizing the chance of satisfying packet delay budget of M2M traffic. We also introduce a new performance metric called "Effective Allocated Bits/RB pair" to measure the allocation efficiency of a scheduler, evaluate the performance of the proposed scheduler in terms of this metric and identify the scope of possible improvements.**

***Keywords*—LTE, TDD, uplink, packet scheduler, M2M, efficiency, delay sensitive**

I. INTRODUCTION

Machine-to-Machine (M2M) communications is significantly different from human to human (H2H) communications in a number of ways, thus imposing new system design challenges for next generation mobile broadband networks. M2M traffic is typically characterized by a large number of autonomous devices transmitting small amounts of data with a range of Quality-of-Service (QoS) requirements, which introduces an uplink-biased trend requiring an efficient uplink resource allocation scheme. In particular, some M2M applications such as monitoring and control require extremely low latency communications. The Long Term Evolution (LTE) standard is an attractive solution for M2M communications because of its optimized all-IP architecture, low latency, high capacity and flexible radio resource allocation mechanism in a time-frequency grid.

Nevertheless, the LTE standard has been designed and optimized for human end user applications e.g. voice, video conferencing, online gaming, video streaming and file transfers where the sessions are typically quite long-lasting and mean per-user data rate is the most important performance metric [1], while maintaining certain well-defined end-to-end delay constraints. The maximum-rate scheduling paradigm attempts to maximize the spectral efficiency by prioritizing high data-rate users having good Signal to Noise Ratio (SNR) whereas the proportional fair one ensures a minimum data rate for all users. But these scheduling schemes are inappropriate for M2M traffic because of the associated large number of devices generating small, short-lived transactions with diverse QoS constraints in terms of latency and/or reliability. In particular, the notion of a mean target data rate is meaningless for an M2M application in which a device might only send a small number of packets sporadically.

M2M devices can have different delay tolerances [2] based on their applications, ranging from a few milliseconds (ms) to several minutes or even hours. In addition, some M2M devices might not have a large amount of memory to store data which is pending transmission. Therefore the LTE eNodeB uplink scheduler should prioritize the devices that have packets approaching their delay budget limit and allocate them enough resources to transfer their data before the associated deadline while avoiding a buffer overflow.

The LTE standard supports both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) [3] modes with TDD possibly being more suitable for a private M2M communications network because of its lower cost of spectrum and equipment. In addition, the seven different uplink/downlink allocation configurations [4] of LTE TDD provide an opportunity to support asymmetric traffic requirements and can result in better utilization of resources, particularly for M2M traffic which is usually uplink biased. Although, among the seven, TDD configuration 0 supports the highest uplink capacity (with 6 uplink subframes/frame) to accommodate uplink-heavy M2M traffic, the performance bottleneck might originate from the Physical Downlink Control Channel (PDCCH) [4] because of scarce downlink resources to convey the uplink grants. Since dynamic scheduling in the LTE standard consumes the PDCCH capacity to carry each uplink grant, effort to ensure fairness among a large number of M2M devices might result in congestion of the PDCCH resources. If the PDCCH becomes saturated before the data carrying Physical Uplink Shared Channel (PUSCH) [4], one approach of a typical LTE scheduler might be assigning the rest of the PUSCH resources among already allocated uplink users. This approach is suitable for increasing the data rate of typical datahungry applications since they are likely to have enough data waiting in their buffers to fully utilize the incremental uplink resources. But this is not always the case with M2M communications because M2M devices typically send small data volumes sporadically, so they typically have no additional data to send beyond their existing allocations. Another concern with M2M data is that the header overhead incurred when transferring small payloads is significant and results in poor effective data transfer in spite of high channel utilization. So the effective data transfer capability of the packet scheduler should also be considered as an important performance metric, especially for M2M communications.

Therefore, devising an efficient uplink packet scheduler which satisfies the diverse QoS requirements of M2M devices as well as ensures effective resource utilization of the LTE radio resources can be a stepping stone for smooth integration of M2M communications within the LTE standard. Some previous works [5] [6], addressed the issue of high PDCCH utilization for M2M traffic in LTE and proposed QoS-clustering and group-based access for M2M devices. The authors proposed fixed allocated access grant time intervals (AGTI) in [7] where each M2M device in each cluster is allocated one Resource Block (RB) [4] to transmit at most one packet in the corresponding AGTI. Although this technique mitigates the PDCCH utilization issue, it is not suitable for event-based M2M traffic with variable burst size. The authors in [8] proposed a modification of the AGTI scheme for Poisson-modelled event-based traffic and showed improved delay performance by prioritizing the M2M devices based on their queue-size. However, they assumed fixed size requests from the M2M devices and fixed bit carrying capacity per RB. Our proposed scheduler combines the earliest-deadline-first approach with queue-awareness for Poisson-modelled event-based M2M traffic with variable burst size.

The main contributions of this paper are:

- Instead of assuming fixed capacity RBs, we show how scheduling devices for a variable number of RBs based upon the size of their queues can increase efficiency and we propose a new metric for efficiency measurement of an LTE packet scheduler i.e. effective allocated bits/RB pair.
- We compare the performance of our proposed enhanced delay sensitive uplink scheduler to an equal capacity fair scheduler for LTE TDD configurations 0 and 1 in the context of data and control channel utilization, the probability of satisfying delay budget and effective allocated bits/RB pair.

The rest of the paper is organized as follows: in section II, we discuss the LTE dynamic scheduling scheme and identify the possible limitations when employed for M2M traffic. We also explain the proposed metric i.e. effective allocated bits/RB pair for efficiency evaluation of the LTE packet scheduler. In section III, our proposed uplink scheduling algorithm for delay sensitive M2M devices is described. Section IV covers the simulation parameters and section V includes the results and discussion. Conclusions and scope of future work is outlined in section VI.

II. Design Considerations and Efficiency Metric

A. *Resource Allocation in LTE TDD*

In LTE, the role of resource allocation is to dynamically assign available time-frequency resources to different User Equipments (UEs). The basic unit of resource allocation is a Physical Resource Block (PRB) pair, where a PRB occupies 12 sub-carriers (180 kHz) in the frequency domain and 1 slot (0.5 ms) in the time domain [4]. An uplink resource grant which is also known as a Transport Block (TB) [9] for an UE applies for 1 subframe (duration 1ms, consisting of 2 slots) and spans a bandwidth of $N_{PRB} \times 180$ kHz, where N_{PRB} is the number of contiguously allocated PRBs to that UE on the PUSCH. The number of available PRBs for the PUSCH is given by the channel bandwidth after deducting the number of PRBs reserved for the Physical Uplink Control Channel (PUCCH) [4]. For instance, a 3 MHz LTE system has 15 PRBs in the frequency domain and if 2 PRBs are reserved for the PUCCH, 13 PRBs remain for the PUSCH for every uplink subframe.

In the case of TDD, the same spectrum is switched between uplink and downlink in the time domain and the number of uplink subframes per frame is defined by the TDD configuration. Table I lists the uplink/downlink allocation scheme of an LTE TDD frame for configurations 0 and 1. Uplink and downlink subframes are denoted as ‘U’ and ‘D’ respectively. Subframes marked ‘S’ are special subframes to act as a guard period between downlink to uplink switches and may also serve as reduced capacity downlink subframes.

Table I: Frame structure of LTE TDD Configuration 0 and 1

10 ms TDD Frame										
Configuration	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D

B. *Uplink Scheduling and Delay Components*

Assuming a UE is already in the RRC_CONNECTED [10] state, when it is has data to send, it first waits for an opportunity to transmit a Scheduling Request (SR) [11] on the PUCCH. The waiting time can be variable depending on its pre-assigned SR offset and also the position of the next uplink subframe in the case of TDD. Once an SR is received from a UE, the eNodeB packet scheduler queues the request and determines a corresponding grant for the PUSCH. The grant is then signaled to the UE on the PDCCH. The UE continuously monitors the PDCCH channel while not asleep due to Discontinuous Reception (DRX) and upon receiving its grant, it has to wait a certain number of subframes (for TDD, it is determined from a look up table in [9] and can be between 4 and 7 subframes) before it can send its actual data on the PUSCH. If the grant cannot accommodate its entire data, the UE indicates the size of the remaining data in a MAC control element known as the Buffer Status Report (BSR) [11]. The eNodeB scheduler assigns the next grant to the UE using the same procedure, but this time with more detailed knowledge about the volume of pending data at the UE by virtue of the buffer status knowledge.

As discussed above, the components of the uplink delay (from the packet generation to the packet reaching the eNodeB) consists of the waiting time of a packet at the UE buffer before sending an SR/BSR, the scheduling delay of the eNodeB to assign a grant and the time until the UE sends the data on the PUSCH after receiving the grant. The delay sensitive M2M devices have stringent Packet Delay Budgets (PDBs) and the scheduler needs to accommodate all the uplink delay components within the PDB to meet their requirement.

C. Performance Limitations Due to M2M Traffic

M2M communications is typically characterized by small data bursts generated from a large number of devices, with a wide variation in delay budgets. The uplink-biased TDD configurations (e.g. TDD configuration 0) come at a cost of fewer downlink subframes and hence less PDCCH resources. Eliciting grants to a large number of devices in a fair manner requires more PDCCH resources. As a result, the PDCCH might be exhausted before the PUSCH leading to a situation where no more uplink grants can be conveyed to the devices leaving many packets waiting in the device buffers and causing high uplink delays and packet loss and also wasting the PUSCH resources.

The Transport Block Size (TBS) is the maximum bit carrying capacity of an allocation (TB). The TBS index (I_{TBS}) is determined from the Modulation and Coding Scheme (MCS) index (I_{MCS}) [9]. Table 7.1.7.2.1-1 in [9] shows the TBS values for different values of I_{TBS} and the number of PRBs (N_{PRB}). From the table characteristics it is observed that for a given I_{TBS}, the TBS increases with N_{PRB}. It can also be determined that for a given I_{TBS} the bit carrying capacity of an RB pair also increases with increasing N_{PRB}. For example, for I_{TBS} = 20, the table entry shows TBS = 440 when N_{PRB} = 1, i.e. the bit carrying capacity of 1 RB pair = 440 bits. But for the same I_{TBS}, the table entry shows TBS = 2344 when N_{PRB} = 5, i.e. the bit carrying capacity of 1 RB pair = 468 bits (approximately). Therefore, for the given I_{TBS}, around 6 % extra bits can be carried per RB pair if one UE is assigned 5 RB pairs in the same uplink subframe instead of 1 RB pair allocations in 5 different subframes. Thus, it is more spectrally efficient to allocate more RB pairs to a single UE rather than splitting the available RB pairs among a number of devices, provided that the single UE has enough data to utilize its allocated RB pairs to the fullest. It would also result in lower PDCCH utilization.

M2M devices typically ask for sporadic small grants due to their small data volume. Therefore, trying to maximize the number of devices served in a subframe leads to small grants per device, high PUSCH utilization yet poor spectral efficiency in regard to the bits served per RB pair.

Including the UE buffer size in the scheduling metric is important for M2M traffic in order to assign timely grants, to increase spectral efficiency and to reduce control overhead.

D. Effective Allocated bits/RB pair

The PUSCH utilization is the ratio of occupied RBs to the total available RBs, irrespective of the efficiency of intra-RB capacity usage. Due to the typically small size of an M2M payload, header overhead often leads to a low ratio of payload bits to total bits. When a UE is assigned an uplink allocation (TB) of a certain TBS, it constructs a MAC PDU which includes MAC header, MAC control elements and MAC SDU(s) [11]. The maximum size of the MAC PDU is equal to the TBS and therefore, the maximum permissible size of the MAC payload (i.e. MAC SDU) is given by subtracting the bits consumed by MAC header and MAC control elements from the TBS. Fig.1 illustrates this assuming a single logical data channel used by an M2M device.

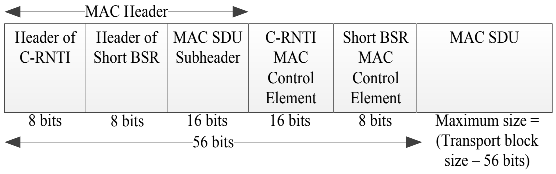

Fig. 1: Construction of a MAC PDU

For a small grant, the header bits take away a significant percentage of the allocated bits. Therefore, to transfer a certain amount of payload, an M2M device for which the data appears sporadically over time would require several small grants and would incur a header penalty with each such grant.

Another source of inefficiency could arise from partially utilizing the TBS. The maximum number of bits that can be allocated to build the MAC PDU is defined by the TBS, but there can be a situation where the number of available bits at the UE buffer does not exactly match the TBS. If the scheduler allows an UE to transmit its full buffer and the UE buffer size is n_b bits, where TBS ($N_{PRB} = N$) < n_b < TBS ($N_{PRB} = (N+1)$), then allocating (N+1) PRBs for that UE wastes some bit carrying capacity of the last PRB. On the other hand, allocating N PRBs would leave some of the bits in the UE buffer which would require another grant (increased delay for some packets and requirement of another PDCCH resource and also causing header overhead). So a trade-off situation arises here and requires an efficiency metric to determine the optimum allocation policy.

Therefore, to evaluate the efficiency of a scheduler, especially for M2M traffic, we define a new metric called effective allocated bits/RB pair (pairing is done in the time domain i.e. 2 RBs occupy same frequency band but 2 consecutive slots in the subframe) which is defined as follows:

$$\textit{Effective allocated bits/PRB pair} = \frac{n_b - h_b}{N_{PRB}} \quad (1)$$

Where, n_b = number of allocated bits for the MAC PDU
h_b = number of bits consumed by MAC header and MAC control elements
N_{PRB} = number of allocated PRB(s) in frequency domain

However, the effective bits correspond to the MAC layer payload i.e. MAC SDU size. The higher layer (e.g. IP/UDP) header bits are included in the MAC SDU and thus part of the effective bits. So this efficiency is from a MAC layer effective payload transfer viewpoint.

For the example given in section II.C, for N_{PRB} = 1, TBS = 440.

Assuming, n_b = TBS,

$$\textit{Effective allocated bits/RB pair} = \frac{n_b - h_b}{N_{PRB}} = \frac{440-56}{1}$$

$$= 384 \textit{ bits /RB pair}$$

Again, for $N_{PRB} = 5$, TBS = 2344, assuming n_b = TBS,

$$\textit{Effective allocated bits/RB pair} = \frac{n_b - h_b}{N_{PRB}} = \frac{2344\text{-}56}{5}$$

$$= 457.6 \textit{ bits /RB pair}$$

By considering the header overhead, we comprehend that for the given MCS value, around 19% extra effective bits can be carried per RB pair by assigning 5 RB pairs at a time to 1 UE instead of 5 different grants each of 1 RB pair, if the TBS is utilized fully.

The impact of partially utilizing the TBS can be demonstrated by an example where, $n_b <$ TBS,

Assuming, n_b = 1950 bits, $N_{PRB} = 5$ is required to fully accommodate 1950 bits for $I_{TBS} = 20$, then,

$$\textit{Effective allocated bits/RB pair} = \frac{n_b - h_b}{N_{PRB}} = \frac{1950\text{-}56}{5}$$

$$= 378.8 \textit{ bits /RB pair}$$

Thus the occurrence of partially filled PRB can largely reduce the efficiency especially when large grants are allocated.

By using the effective allocated bits/RB pair metric we can measure how efficiently the intra-RB capacity is being utilized. Including this metric in the scheduling algorithm can also help with optimizing the grant sizes.

III. Proposed Delay Sensitive Uplink Scheduler

To accurately predict the deadline for providing an uplink grant to a UE so that its packets do not exceed their delay budget, we propose a new MAC control element i.e. Packet Age (PA), which informs the scheduler about the waiting time of the oldest packet in the UE buffer along with the buffer size reported in the BSR. It needs 1 byte in addition to the standard BSR and is sent only if there is data left in the buffer after filling an uplink grant. Using this method, the eNodeB can take into account the time spent by a packet in the UE buffer and determine the maximum scheduling delay the UE can tolerate. For the initial SR, the PA is assumed to be the highest possible value i.e. equal to the SR periodicity [9].

The deadline is calculated as below:

$$D = t + T_{PDB} - T_{PACKET\text{-}AGE} - T_{POST\text{-}GRANT} \qquad (2)$$

Where, D = deadline for the request being served
t = time when the request is received by the eNodeB
T_{PDB} = PDB of the requesting UE

$$T_{PACKET\text{-}AGE} = \begin{cases} \textit{communicated Packet Age, for BSR} \\ \textit{SR Periodicity, for SR} \end{cases}$$

$T_{POST\text{-}GRANT}$ = time gap between reception of a grant and sending the actual packet, as per the look-up table [9]

For uplink scheduling, the eNodeB packet scheduler ranks the pending requests in descending order of an urgency metric U which is a function of the deadline and the buffer size as given in (3).

$$U_i = \begin{cases} \frac{B_i}{\max\{B\}} \cdot \frac{T_{SF}}{(D_i - t)}, & D_i - t > 1 \\ 1, & D_i - t \leq 1 \end{cases} \qquad (3)$$

Where, U_i = urgency metric for request i
B_i = BSR index of request i corresponding to a buffer size as defined in [11]
$max\{B\}$ = maximum BSR index i.e. 63
T_{SF} = LTE subframe duration, fixed at 1ms
t = current time (ms)
D_i = deadline for request i (ms)

The requests with high urgency metric are served first giving the requests with critical deadline the highest priority. Including the buffer size index of the UE in the urgency metric helps avoid buffer overflow of the UE and increases the spectral efficiency as well.

IV. Simulation Model

We compare the performance of our proposed delay sensitive scheduler with a reference equal capacity fair scheduler for LTE TDD configurations 0 and 1. The equal capacity fair scheduler maximizes the number of UEs with pending data served per subframe by distributing the available resources evenly among them.

We used an input traffic model having different classes of delay sensitive bursty M2M traffic (A, B, C and D) with different uplink PDB. The characteristics of these traffic classes are described in Table II. The inter-arrival times of the requests have an exponential distribution with a mean arrival rate specified in the Table II for an offered uplink load of 4 Mbps. Each request also generates a packet burst where the inter-arrival times between the packets of a burst also follow an exponential distribution with a mean of 1 ms.

Table II: M2M Traffic Model

Device Class	Number of Devices	Mean Arrival Rate (requests /sec)	Number of Packets/ request	Packet Size[1] (bytes)	Delay Budget (ms)
A	15	112.5	1	32	20
B	15	37.5	Uniform (5,10)	32	40
C	15	4.50	Uniform (5,20)	32	80
D	15	56	Uniform (1,3)	32	250

[1] Packet size is defined at the application layer, the IP/UDP header adds another 28 bytes

We used the OPNET simulator applying the parameters listed in Table III.

Table III: Simulation Parameters

Parameter	***Value***
Frequency Band	3GPP Band 37 [12] (1910-1930 MHz uplink / downlink)
Mode	TDD configurations 0 and 1
Channel bandwidth	3MHz
Cyclic prefix type	Normal
Maximum device Tx power	0.2W
Maximum eNodeB Tx power	5W

Device Rx sensitivity	-110dBm
eNodeB Rx sensitivity	-123dBm
Device antenna gain	-1dBi
eNodeB antenna gain	15dBi
Device height	1.5m
eNodeB height	40m
SR periodicity	10ms
PUCCH channels	2
HARQ re-transmissions	Supported
Channel model	Suburban fixed Erceg model with Terrain Type C [13]
Radio access network model	Single cell, 3km radius (28.27 km^2)
Grant size for SR requests	520 IP layer bits (corresponds to B_i = 13 in Eq. (3))

V. RESULTS

Fig. 2 compares the mean PUSCH utilization for the delay sensitive scheduler and the reference scheduler for TDD configurations 0 and 1. As configuration 1 has only 4 uplink subframes per frame, it offers relatively less uplink capacity and the PUSCH is saturated for an offered load of 2.5 Mbps.

For configuration 0, the delay sensitive scheduler supports up to 4 Mbps load where almost 100% PUSCH capacity is utilized. But the reference scheduler fails to carry beyond 3 Mbps load, in spite of having only around 85% PUSCH utilization.

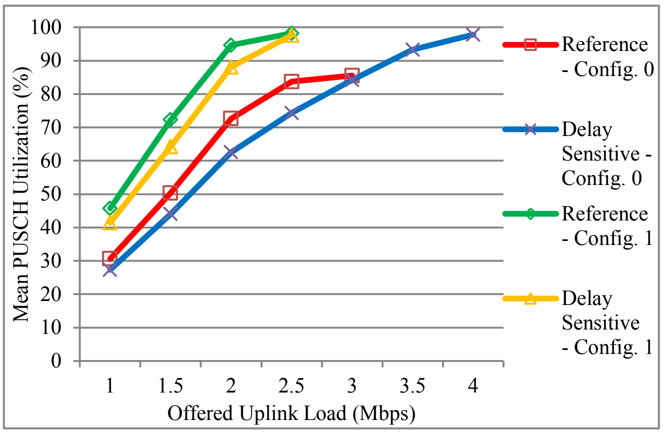

Fig. 2: Mean PUSCH Utilization

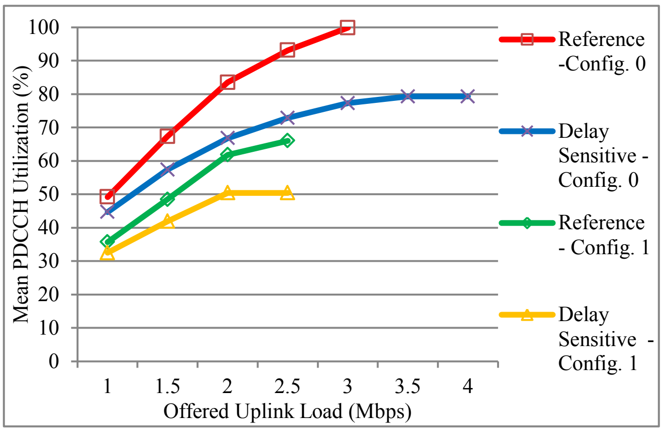

Fig. 3: Mean PDCCH Utilization

Fig. 3 explains the fact that this situation occurs due to the saturation of PDCCH with 3 Mbps offered load in case of the reference scheduler for TDD configuration 0. But the delay sensitive scheduler's capacity is not control channel limited as it shows less than 80 % PDCCH utilization even when PUSCH is utilized to the fullest.

Fig. 4 shows the probability of a packet meeting its delay budget for both schedulers for TDD configurations 0 and 1. It is observed that although the delay sensitive scheduler performs well for both configurations up to 2 Mbps load, it degrades for configuration 1 if the load is further increased as the PUSCH becomes saturated. For configuration 0, the delay sensitive scheduler can consistently guarantee almost every packet to meet its delay budget up to 3.5 Mbps load and for an offered load of 4 Mbps, there is still 88% chance that a packet would be transferred within its delay budget.

With the reference scheduler, the probability of meeting the PDB becomes half when the PUSCH is congested for TDD configuration 1 at an offered load of 2.5Mbps. For TDD configuration 0, its delay performance deteriorates more sharply than the delay sensitive scheduler with increasing load. The reference scheduler ends up with 80% packets meeting their delay budget for a load of 3 Mbps.

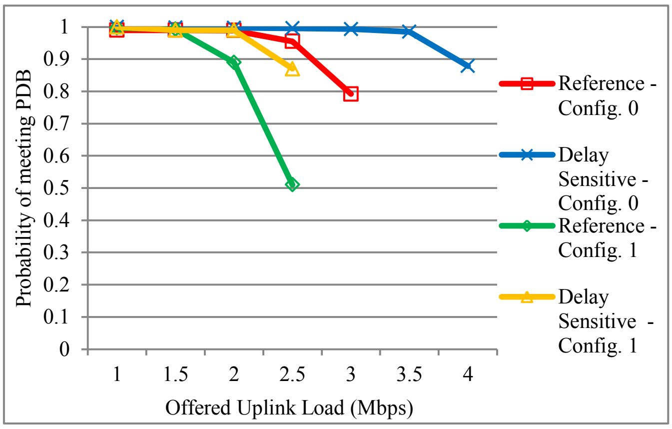

Fig. 4: Probability of meeting PDB

Fig. 5 shows the mean number of RBs allocated per uplink grant for both of the schedulers for TDD configuration 0. The trend shows that with increasing load, the mean grant size (N_{PRB}) decreases for the reference scheduler. But for the delay sensitive scheduler, the mean grant size increases with increasing load.

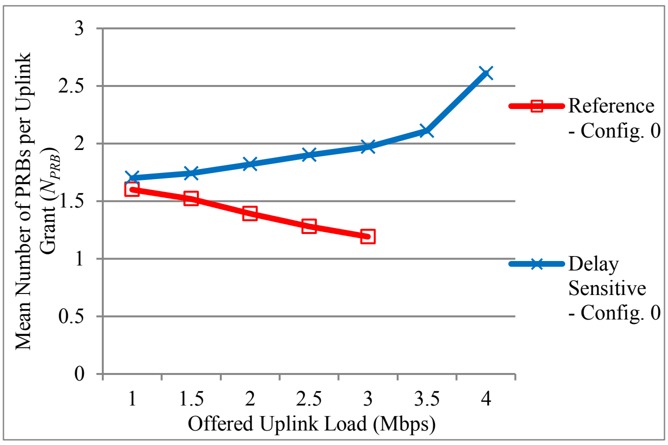

Fig. 5: Mean Number of PRBs per Uplink Grant (N_{PRB})

Fig. 6 shows the mean values of the effective allocated bits/RB pair for both of the schedulers for TDD configuration 0. In spite of having lower values of the mean grant size, the equal capacity reference scheduler achieves similar performance for 1 Mbps and 1.5 Mbps load.

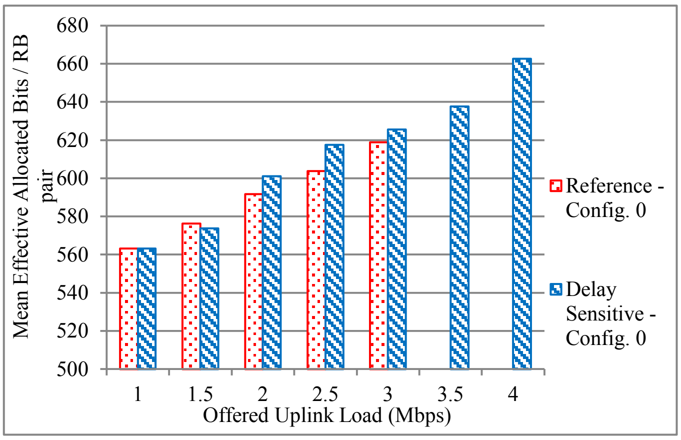

Fig. 6: Mean Effective Allocated Bits/RB pair

With increasing load, the mean effective allocated bits/RB pair values increase for the reference scheduler despite the decreasing grant sizes. The reason behind this behavior is the fact that now the already allocated RBs tend to be more highly utilized. The UEs get smaller grants relative to their buffer sizes and try to make the best use of the grants diminishing the chance of having partially filled up RBs.

As the load increases from 2 to 3 Mbps, the mean grant size for the delay sensitive scheduler also increases and the effective allocated bits/RB pair increases accordingly. Although the delay sensitive scheduler has higher possibility of partially filled up RBs, it performs better than the reference scheduler for higher loads because the positive effect of increasing grant size overpowers the negative effect caused by partially filled up RBs.

From the above observation we can determine that the presence of partially filled up RBs has a negative impact on the performance of the delay sensitive scheduler. If all the allocated RBs were fully utilized, the delay sensitive scheduler would have always been able to achieve higher effective allocated bits/RB pair, but at the probable expense of missing deadlines for some packets. This is an important remark for further enhancement of the proposed scheduler where the scheduling algorithm would try to match number of allocated bits to the TBS as closely as possible within the delay constraints.

VI. Conclusion and Future Work

In this paper, we analyzed the performance of our proposed uplink scheduler for LTE TDD, which employs a new MAC control element i.e. PA to accurately predict the deadline of delay sensitive M2M data and schedule the requests according to a combination of their deadlines and buffer sizes. The system capacity for the delay sensitive scheduler remains data channel limited even for TDD configuration 0 which has the lowest available control channel resources and it also outperforms an equal capacity fair scheduler by ensuring 88% probability of satisfying PDB at full load.

We also introduced a new efficiency metric for the allocation efficiency measurement of a scheduler and evaluated the metric for both schedulers. We concluded that combining the delay sensitive scheduler with a TBS best-fitting strategy would eliminate the disadvantage of having partially occupied resources. Another approach could also be multiplexing two UEs in time domain to share the RB pair to achieve higher effective allocated bits/RB pair [14]. Our future work will concentrate on revisiting the delay sensitive scheduling algorithm to explore these possible solutions. Besides, the effect of HARQ-retransmissions on delay budget performance is not taken into account here since we assume all the UEs are stationary and have good channel conditions. Incorporating the channel condition and group-based scheduling within the delay sensitive scheduler framework are part of our future research.

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