Energy Efficient Scheduling in LTE-Advanced for Machine Type Communication

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Abstract—Machine Type Communication (MTC) is gaining an enormous interest among communication industry and academia all around the world. The variety of services offered by MTC is expected to significantly increase the number of MTC Devices (MTCD) on wireless networks. The huge number of MTCD poses several challenges to cellular network operators such as efficient radio resource management, energy efficiency (EE) etc. Two main radio resource management techniques to support MTC over 4G Long Term Evolution (LTE) were proposed in the literature: Group Based Scheduling (GBS) and Time Granularity Scheduling (TGS). In this paper, we compare the EE of GBS and TGS by formulating a general expression for the downlink transmit power by eNodeB. The numerical results show that the GBS is more energy efficient that TGS under given quality of service constraints.

Keywords— Machine Type Communications; Long Term Evolution-Advanced; Radio Resources Management; Group Based Scheduling; Time Granularity Scheduling; Energy Efficiency.

I. INTRODUCTION

The 3rd Generation Partnership Project (3GPP) defines machine type communication as the communication between machines or machine to network with little or without human intervention [1]. MTC is predicted to play a significant role in the future wireless communications (i.e. 5G and beyond) [2]. MTC aims to provide ubiquitous connectivity to a variety of devices in smart metering, telematics, automobile, smart cities etc. [3]. It is predicted that the number of MTCDs will be in the order of 100 billion by 2022 [2]. This extraordinary increase in the number of connected devices raises several challenges for the Mobile Network Operators (MNOs).

Supporting billions of MTCD with distinct and varying traffic characteristics is considered as one of the main challenge for MNOs. MTC traffic characteristics significantly differ from human-to-human (H2H) cellular communication: small amount of data packets, infrequent data packets, delay tolerance etc. [3]. Currently, MTCD tend to use General Packet Radio Service (GPRS) to get an immediate market entry, as GPRS is an internationally deployed standard with excellent coverage. However, GPRS offers relatively low spectral efficiency and the predicted number of MTCD requires a highly spectral efficient mobile network [4].

3GPP introduced LTE in release 8 as a spectral efficient network. LTE is designed to provide higher spectral efficiency, low latency and data rates to meet goals set by International Telecommunication Union (ITU). In order to achieve these goals, the LTE uses flexible RRM techniques to enhance the MAC and physical layer functionalities, such as Adaptive Modulation and Coding (AMC), Channel Quality Indicator (CQI) reporting and resource sharing. Later, 3GPP introduced LTE-Advanced (LTE-A) in release 10, which provides additional functionalities such as extended MIMO, heterogeneous networks and Carrier Aggregation (CA) [5].

LTE is a promising solution for H2H communications and able to provide some benefits to MTC such as coverage, mobility support, fully standardised etc. However, it is still far from ideal for MTC due to the RRM and scheduling challenges caused by the unique MTC traffic characteristics. Therefore, in recent years a considerable amount of research effort has been devoted to find ways to adapt LTE network for MTC [4][6][8].

In the literature, GBS and TGS were introduced as RRM techniques to handle MTCD over LTE network [4]. GBS forms group (also known as clusters) of connected MTCDs and treat them as an individual device [6]. On the other hand, TGS exploits the similarity between MTC traffic and Voice over IP (VoIP) traffic to propose a scheduling algorithm for MTC [4][8]. Although, MTC is one of the most active research area, very little effort has been dedicated to investigate the EE of scheduling for MTC over LTE-A. For instance, GBS was introduced and a grouping algorithm was proposed in [6]. Similarly, Antonis et al. [4] enhanced the performance of GBS and TGS and proposed recommendations to adapt LTE network for MTC. However, both [4] and [6] evaluated the MTC RRM performance without paying much attention to the EE of the scheduling algorithms.

In this paper, we analyse the EE of the GBS and TGS schemes for MTC over LTE-A. Firstly, we give a brief introduction of the state-of-the-art MTC schedulers for LTE/LTE-A in section II. Our system model is presented in section III. Afterwards, we derive a general expression to evaluate the eNodeB total transmit power needed to provide an acceptable Quality of Service (QoS) in section IV. We evaluate and discuss the EE of both scheduling schemes numerically based on the downlink power transmit by eNodeB and the system model in section V. Finally, section VI conclude this paper.

II. MTC LTE/LTE-A SCHEDULERS

To overcome the challenges of how to support MTC over an existing LTE network, GBS and TGS schemes were introduced in the literature [4][6][8].

A. Group Based Scheduling (GBS)

The MTC traffic characteristics and diverse Quality-of-Service (QoS) requirements highlighted GBS as a suitable...
RRM technique to provide a ubiquitous connectivity to a large number of MTCDs. The main concept of GBS is to group the MTCDs based on their QoS requirements (Γ) and the maximum tolerable jitter (Υ). A grouping algorithm for GBS was introduced in [6] and a flowchart of the algorithm is shown in Fig. 1, where Υ' can be obtained by Υ' = τ + Σg=1 G−1[Γm/Γg] for g = 2,…,G, where G is the total number of groups and τ is the length of the time determined for MTCD to access the physical resource blocks (PRB). Therefore, the eNodeB manages and transparently connected to each MTCD through the cluster.

GBS significantly reduces the signalling overhead without creating any impact on the wireless links reliability. Additionally, the RRM scheduling complexity can be considerably reduced. However, the grouping procedure itself may cause some issues [6]. The main concern in the grouping procedure is the limited capacity of the groups. In particular, the main issue occur in the instance of the number of MTCD that belong to a particular group exceeds the scheduled PRBs capacity [9].

B. Time Granularity Scheduling (TGS)

TGS is introduced in the literature as an alternative RRM technique to support MTCDs over LTE network. LTE RRM is optimised to perform it’s scheduling at each Transmission Time Interval (TTI) (i.e. one ms). However, billions of MTCD can impose several constrains to the applicability of such approach [4]. These concerns were previously raised for the VoIP services, as it was also predicted a considerable increase in the VoIP calls [4][7].

In the literature, semi-persistent scheduling was proposed to overcome the massive number of VoIP calls issue [7]. The semi persistent schedulers make its decisions for a longer time period; because it relies on the traffic characteristics to easily predict the traffic [7]. The similarity between VoIP and MTC traffic (i.e. the transmission periodicity and the relatively small amount of data required) motivates using semi persistent scheduling as a possible scheduling candidate for MTC over LTE-A [4].

TGS exploits the concept of semi-persistent scheduler i.e. making the scheduling decision for a longer time interval. Therefore, TGS is able to significantly reduce the number of scheduling decisions. Accordingly, the complexity of handling a tremendous number of MTCDs [4]. On the other hand, in TGS the QoS may suffer due to the random nature of the channel over time [7].

III. SYSTEM MODEL

A. System Overview

We consider a single downlink LTE-A cell with radius R surrounded by ζ cells with CA functionality. Theoretically, with CA up to five component carriers (CC) can be aggregated (as defined in 3GPP release 10 [5]), however, with the current RF front-end technology, CA is able to aggregate only two carriers. Moreover, the current MTCD is not able to use the CA functionality. Nonetheless, in the future it is predicted that the RF technology will be more mature and up to five CC can be aggregated with reasonable complexity. Therefore, in this paper we consider the case of aggregating five 20 MHz carriers to serve the MTCD. We assume that the considered cells characteristics are identical in terms of their shape (i.e. circular), size (i.e. radius size) and MTCDs (i.e. number and requirements).

We consider serving five classes of MTCDs: Smart Meters (SM), Health Sensors (HS), Traffic Sensors (TS), Home Security Systems (HSS) and Surveillance Cameras (SC) as shown in Fig. 2. Each MTCD class has a distinct QoS requirement i.e. minimum throughput and the maximum acceptable QoS constraint violation.

B. GBS Model

As stated in II-A, in GBS the eNodeB treats the group of MTCD (cluster) as a single device. Therefore, the eNodeB RRM scheduler is concerned with a much less number of connected devices than the actual number of MTCDs. Although, all MTCDs in any given group have similar QoS requirements the formed group of MTCDs has different characteristics (i.e. throughput requirements and transmission periodicity) [1]. Therefore, we can approximate the traffic characteristics of the group as a full buffer traffic model (constantly transmitting data). Moreover, we assume that the minimum throughput requirement of the group is equal to the summation of all the MTCDs minimum throughput within each group.

In order to evaluate the performance of GBS, we assume two grouping scenarios. The scenarios differ in the number of MTCDs in each group i.e. the first grouping scenario (GBS-S1) forms smaller groups with respect to the groups in the second scenario (GBS-S2). Accordingly, the throughput requirements for GBS-S1 are also less than the GBS-S2. The number of

![Fig. 1. GBS grouping algorithm [6]](image)

![Fig. 2. MTCD classification](image)
groups in each MTCD class also differs. Fig. 3 illustrates both grouping scenarios in terms of the number of MTCD groups per class with respect to the total number of MTCD in the given cell.

![Fig. 3 Group Based Scheduling proposed Scenarios](image)

C. TGS Model

The TGS makes its scheduling decision for a longer time interval than the standard LTE scheduling interval (i.e. one TTI). Moreover, each MTCD class has its distinct characteristics and requirements. The MTCD traffic characteristics (i.e. transmission periodicity and relatively small amount of data transmission) can be approximated as a VoIP traffic model (i.e. a two states Markov chain model) [8] as shown in Fig. 4. The first state (i.e. ‘ON’) indicates that the MTCDs are transmitting data. On the other hand, the second state (i.e. ‘OFF’) refers to the standby state. Where, $A_\varsigma$ refers to the probability of changing from ‘ON’ state to the ‘OFF’ state of MTCD class $\varsigma$. On the contrary, $B_\varsigma$ refers to the probability of changing from state ‘OFF’ to ‘ON’ state of class $\varsigma$.

![Fig. 4 TGS Traffic Model](image)

\section*{IV. TOTAL TRANSMIT POWER BY eNODEB}

In this section, we present a general expression to calculate the total power transmitted by the eNodeB in downlink to satisfy the QoS requirements for each MTCD class using both scheduling algorithms. The signalling overhead for both scheduling algorithms is outside the scope of this paper. The received Signal to Noise plus Interference Ratio (SINR) at the $i^{th}$ MTCD/group is subject to the power received by the $i^{th}$ MTCD/group ($P_{Ri}$), the power of the interfering signals form the surrounding cells ($I$) and the Additive White Gaussian Noise (AWGN) power ($n_o$). Therefore, the received SINR at the $i^{th}$ MTCD/group is given as,

$$\text{SINR}_i = \frac{P_{Ri}}{I + n_o} \quad (1)$$

where $P_{Ri}$ is subject to Fast Fading Gain (FFG) and has a random value according to the channel state, distance between the $i^{th}$ MCTD/group and the eNodeB is $D_i$, path loss is $\alpha$ and the power transmitted by the eNodeB to the $i^{th}$ MCTD/group is $P_T$. Accordingly, the received power $P_{Ri}$ can be expressed as,

$$P_{Ri} = P_T \times \text{E}[\text{FFG}] \times D_i^{-\alpha} \quad (2)$$

where $\text{E}[\cdot]$ donate to the expectation operator.

The interfering signals from the surrounding cells assumed to have the same characteristics (i.e. transmit power and the fast fading) as the transmitted signal. On the contrary, the distance between the MTCD/group and the surrounding eNodeBs ($D_{ij}$) differs. Therefore, the interference power can be expressed as,

$$I = \sum_\varsigma P_{T \varsigma} \times \text{E}[\text{FFG}] \times D_{ij}^{-\alpha} \quad (3)$$

In order to calculate the eNodeB transmit power for MTCD under strict QoS requirements in a cell; the instantaneous achieved throughput by $i^{th}$ MTCD within MTCD class $\varsigma$ ($\theta_{\varsigma \text{inst}}$) must exceed the minimum required throughput of that particular class ($\theta_\varsigma$). Therefore, the probability of the maximum accepted throughput requirement violation for MTCD in class $\varsigma$ ($q_\varsigma$) can be expressed as,

$$q_\varsigma < \Pr\{\theta_{\varsigma \text{inst}} < \theta_\varsigma\} \quad (5)$$

where the instantaneous throughput $\theta_{\varsigma \text{inst}}$ can be expressed as,

$$\theta_{\varsigma \text{inst}} = \beta_\varsigma \text{eff} \log(1 + \text{SINR}_i) \quad (6)$$

where $\beta_\varsigma \text{eff}$ is the effective bandwidth assigned to the MTCD/group in category $\varsigma$. Therefore, substituting (6) in (5),

$$q_\varsigma < \Pr\{\theta_{\varsigma \text{eff}} \log(1 + \text{SINR}_i) < \theta_\varsigma\} \quad (7)$$

or

$$q_\varsigma < \Pr\left\{\frac{\theta_\varsigma}{\theta_{\varsigma \text{eff}}} - 1 < \text{SINR}_i\right\} \quad (8)$$
from (1), (2) and (8),

$$ q_c < Pr \left( \frac{\theta_c}{2^{\beta \phi_c}} - 1 < \frac{P_T \times E[FFG] \times D_i^{-a}}{I + n_o} \right) \quad (9) $$

The transmitted power can be assumed as an exponential function with respect to their achieved throughput. Therefore, $q_c$ can be express as the Cumulative Distribution Function (CDF) as follows,

$$ q_c = 1 - e^{\mu \times ENTP_{i_{\text{min}}}} \quad (10) $$

where $ENTP_{i_{\text{min}}}$ is the minimum power required to achieve the QoS throughput constraint for the $i^{th}$ MTCD/group, and $\mu$ is the mean value of $P_T$, and can be obtained by,

$$ \mu = \frac{E[FFG] \times D_i^{-a}}{\left( \frac{\theta_c}{2^{\beta \phi_c}} - 1 \right) \times (I + n_o)} \quad (11) $$

The minimum total power transmitted by the eNodeB to the MTCDs to maintain the QoS ($ENTP_{i_{\text{min}}}$) can be expressed as,

$$ ENTP_{i_{\text{min}}} = \frac{\left( \frac{\theta_c}{2^{\beta \phi_c}} - 1 \right) \times (I + n_o) \times \ln(1 - q_c)}{E[FFG] \times D_i^{-a}} \quad (12) $$

to simplify let,

$$ \alpha = \frac{(I + n_o) \times \ln(1 - q_c)}{E[FFG] \times D_i^{-a}} \quad (13) $$

accordingly (12) can be expressed as,

$$ ENTP_{i_{\text{min}}} = \alpha \left( \frac{\theta_c}{2^{\beta \phi_c}} - 1 \right) \quad (14) $$

The main difference between GBS and TGS traffic is the traffic characteristics (i.e. throughput requirement and periodicity). As mentioned in section III, the GBS traffic can be approximated as full buffer traffic model. On the other hand, TGS traffic can be approximated as VoIP traffic model. Therefore, $\theta_c$ does not only rely only on the MTCD requirements, but the scheduling algorithm also affects it as follows,

$$ \theta_c = \sum_{\gamma} \theta_{\gamma} \quad \text{in case of GBS} $$

$\Delta_c$ is the rate of transitions per second for MTCD of class $\gamma$. $Y$ refers to the number of MTCD in each group, and

$\Delta_c$ is the minimum power required to achieve the

$$ \Delta_c = \frac{1}{\phi_c} \quad (16) $$

where $\phi_c$ is the average transactions per second.

The total power transmitted from the eNodeB to all the considered MTCD/groups ($ENTP$) can be expressed as,

$$ ENTP = \left\{ \begin{array}{ll}
\sum_{\eta} ENTP_{i_{\text{min}}} & \text{in case of GBS} \\
\sum_{\eta} ENTP_{i_{\text{min}}} & \text{in case of TGS} 
\end{array} \right\} \quad (17) $$

where $\eta$ donates to the total number of MTCD devices and $H$ refers to the number of MTCD per group ($H \ll \eta$). Finally, from (14), (15), (16) and (17),

$$ ENTP = \left\{ \begin{array}{ll}
\sum_{\eta} \alpha \left( \frac{\sum_{\gamma} \theta_{\gamma}}{2^{\beta \phi_c}} - 1 \right) & \text{in case of GBS} \\
\sum_{\eta} \alpha \left( \frac{\theta_c}{2^{\beta \phi_c}} - 1 \right) & \text{in case of TGS} 
\end{array} \right\} \quad (18) $$

V. NUMERICAL RESULTS AND DISCUSSION

In this section, both the numerical values and the EE performance of GBS and TGS schemes are introduced. The main numerical values used to obtain the results were presented in Table I.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of eNodeBs per cell</td>
<td>1</td>
</tr>
<tr>
<td>Cells radius $R$</td>
<td>1 km</td>
</tr>
<tr>
<td>Interfering cells</td>
<td>1</td>
</tr>
<tr>
<td>Carrier bandwidth</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Transmission bandwidth</td>
<td>100 MHz</td>
</tr>
<tr>
<td>Number of MTCD per cell $\eta$</td>
<td>$10^3 \times 2 \times 10^3$</td>
</tr>
<tr>
<td>Number of MTCD per group $H$</td>
<td>20-40</td>
</tr>
<tr>
<td>Fast Fading Gain Expectation (E[FFG])</td>
<td>1</td>
</tr>
<tr>
<td>Noise</td>
<td>AWGN</td>
</tr>
</tbody>
</table>
The AWGN noise is subject to the MTCD/group operating temperature ($T$) and bandwidth ($β_{s}^{\text{eff}}$) and can be calculated as $n_{s} = K \times T \times β_{s}^{\text{eff}}$, where $K$ refers to Boltzmann constant. The operating bandwidth ($β_{s}^{\text{eff}}$) is assumed to be evaluated by equally distributing the transmission bandwidth between the MTCD/group according to their throughput requirements.

The MTCDs are assumed to be uniformly distributed into the five main classes. However, each class has its distinct traffic characteristics. Table II presents both the throughput requirements and traffic characteristics for each MTCD class [1].

| MTCD class | θs (kb) | Δs | θs

As mentioned in section III, in order to evaluate the performance of GBS we assumed two grouping scenarios (i.e. GBS-S1 and GBS-S2). GBS-S1 is assumed to contain five MTCD in each group. On the other hand, GBS-S2 is assumed to have 10 MTCD per group.

The total power transmitted by eNodeB under the given QoS requirements with respect to the number of MTCD is presented in Fig. 5. In particular, Fig. 5 presents a comparison between TGS, GBS-S1 and GBS-S2, the values of the power transmitted are normalized by the power transmitted using a traditional scheduling algorithm. The normalizing value is the power needed to satisfy the QoS requirements for a $10^{6}$ MTCD with the same characteristics of the MTCD considered for both scheduling algorithms.

As shown in Fig. 5, the transmit power can be minimised by using GBS. Moreover, GBS-S2 (which has a smaller number of groups per class) requires less power transmitted to satisfy the QoS requirements. For instance, in case of 1500 MTCD connected the eNodeB requires 0.26, 0.53 and 2.22 the normalizing value when using GBS-S2, GBS-S1 and TGS respectively. The reason behind decreasing the transmit power in GBS-S2, is that the number of connections is significantly decreased. However, the grouping algorithm complexity may increase overall power in case of creating huge groups.

VI. CONCLUSION

In this paper, we investigated the state-of-art RRM scheduling algorithms for handling the MTC devices over LTE and LTE-A networks in terms of EE. In particular, we compared the EE of two main scheduling algorithms (i.e. GBS and TGS). We derived a general expression to evaluate the power consumption of each scheduling algorithm downlink according to their traffic characteristics and QoS requirements. The results showed that the power needed to satisfy strict QoS requirements can be minimised by using GBS.

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