Energy Efficiency Analysis of Scheduling in M2M Communication Over Rayleigh Fading Channels

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***ABSTRACT*-Machine-to-Machine (M2M) Communication technology, which enables remote human and machine interaction with physical, chemical and biological systems, is envisaged to generate significant revenues for network operators in mobile communication systems. M2M communication has a wide range of applications such as intelligent transportation systems, health care, smart metering and public safety. Often the employed devices are battery limited. Scheduling of M2M traffic is a challenging task, due to varying QoS characteristics, energy consumption constraints and the massive number of M2M devices. In this paper, we present an energy efficiency analysis of round robin, max throughput and proportional fair scheduling algorithms in the uplink of gateway-assisted M2M communications. Results indicate that the max throughput algorithm is the most energy efficient followed by the proportional fair algorithm and the round robin algorithm.**

***Key words*: scheduling, clustering, machine-to-machine communication, energy efficiency.**

1. INTRODUCTION.

Machine-to-Machine (M2M) Communications which is a type of Information and Computing Technology (ICT) comprising communications, computer and power technologies facilitates interaction of human and machine with physical, chemical and biological systems at a distance [1]. In an M2M system, devices such as sensors and meters are used to collect data and transmit them through communication network to an application where it is translated into meaningful information [2]. M2M communication has a wide range of applications such as intelligent transportation systems, health care, smart metering, public safety, consumer devices, remote monitoring, maintenance etc.

Despites these many applications with its associated improvements in living conditions of our society, M2M communication comes with its own peculiar challenges as compared to the traditional human-to-human (H2H) communications. M2M devices in most cases transmit small amounts of data at a low packet generation rates as compared to current mobile networks, such as Long Term Evolution (LTE), designed for transmitting H2H broadband signals at high data rate [3]. Additionally, M2M have broad range of use cases resulting in their Quality-of-Service (QoS) requirements of traffic to experience large variations for these different applications [4] making it highly difficult for QoS for M2M services in traditional telecom networks to be guaranteed [5]. In order to develop and analyse solutions to these challenges, it is necessary to employ traffic models that represent such services in computer simulations [6].

Furthermore, M2M communications is expected to be deployed extensively in the near future. Majority of these massive machines will be applied in sensing and measurement making it place more pressure on the uplink than on the downlink [3]. This massive nature of M2M communications in cellular networks implies that the scheduling design will become much more complex and challenging, because of the different QoS requirements and traffic volume characteristics of M2M as compared to H2H. The basic principle of scheduling is the dynamic resource allocation in an efficient and fair manner to users based on their data rates and delay constraints needs; meeting these needs is called QoS support [7]. Following [8], scheduling and resource allocation need to consider the inherent limitations on network energy consumption. The massive number of M2M devices will also cause packet collisions in transmissions, resulting in waste of energy. Clustering of devices addresses the massive access problem by reducing the number of concurrent access requests to the base-station. Clustering also increases the lifetime of the devices by reducing the transmission power because of the reduced path loss between a cluster member and the associated cluster head as compared to direct communication between the cluster members and the base station [9]. This is the reason for adopting the clustering technique in this work.

M2M devices are battery limited because large number of them are deployed in areas such as tunnels and underwater where they are not easily accessible, making it technically and economically difficult to either recharge or change the batteries [8]. This calls for an energy consumption performance study and energy efficient design of M2M communications to minimize the energy consumption in wireless communication networks in order to protect the environment from global warming and to facilitate a sustainable development. Scheduling metrics must thus include energy efficiency. Minimizing power consumption and deployment cost in M2M communications are identified in [10] as part of its primary requirements.

2. Related Works

Grouping of M2M devices into clusters based on QoS characteristics and requirements is employed in [11] to manage the manage the massive access complexity of M2M devices to the bases station (BS). The grouped based approach is reported in [12] to reduce energy consumption, provide better QoS performance and lower the signaling overhead. These authors further state that current possible means to improve the grouping method is to form energy efficient group and select the best aggregator or the group head. The clustering design proposed in [13] finds the optimal number of clusters in a cellular network in order to maximize the network energy efficiency. The authors consider a single cell network and thus, interference from other cells is ignored; yet the authors proposed the inclusion of interference in the future work to make the simulation more practical and realistic. Another proposal which did not account for out of cell interference because it considered a single cell scenario, designed an efficient clustering in M2M networks in [14] to minimize energy consumption and increase network lifetime. Inter cluster interference which impacts energy consumption is also not given attention in this work. Similarly, in [15] where the authors stress the importance of a systematic framework to study the power and energy optimal system design in the regime of interest for M2M, a single cell setup with no out-of-cell interference is employed whereas the inclusion of out-of-cell interference in the multi-cell scenario is left as future work. But now in the this work we take a multi-cell scenario and account for the additional effect of out-of-cell interference. According to [16], if inter cluster interference among simultaneous transmission is not properly modelled, it will bring about sub-optimal performance for supporting M2M communications in cellular networks with limited radio resources and tight interference control. It is also identified in [17] that the main problem facing resource allocation which arise and limit performance when multiple users are served concurrently is the inter-user interference.

Scheduling and resource allocation have also been identified to be employed in optimizing the energy consumption in wireless communications. A survey of proposals on uplink scheduling for LTE and LTE-A presented in [3] found that energy efficiency has not been addressed by many proposals. In [9] uplink scheduling and transmit power control were investigated to minimize the energy consumption of battery-driven devices deployed in LTE networks using clustering techniques by distributing massive number of static machine nodes according to a spatial Poisson point process (PPP) in a two-dimensional space. However, the effects of inter and intra cluster interference were not considered. Again, using a single cell scenario, the effect of interference from users in the other surrounding cells is ignored. Yet some of the machine nodes may be located at cell edge and are thus subject to a significant inter-cell interference. Such interference causes reduction of signal quality and waste of energy. It is important that attention is given to these when considering energy optimization schemes. Extensions to [9] is made in [18] with advanced scheduling algorithms some of which are scheduling for narrow band M2M and scheduling over SC-FDMA but still under single model scenario. Narrowband M2M is a 3GPP standard which aims at re-use of existing cellular technology such as GSM and LTE for M2M communication. A competition between M2M and H2H devices for radio resources was studied in [19] which proposed a class based dynamic priority scheduling M2M and H2H traffic in the LTE network. For lifetime of M2M nodes to last longer, scheduling algorithms which aims at efficient use of limited energy should be employed [20]. Aside fulfilling variation in QoS requirements of various applications of massive M2M connections, radio resource management should minimise energy consumption to increase the M2M devices life span [21].

Support for large number of connected M2M devices in the 5th Generation (5G) wireless networks is a critical resource allocation issue [22] which can be solved when the usage of the radio resource and power minimization of the devices are improved [23]. An adaptive fuzzy logic controller-based design is thus proposed in [22] to efficiently allocate uplink resources to several M2M devices ensuring QoS for delay sensitive applications and reduction of devices battery utilization. This work also does not consider inter cell interference since a single cell scenario was employed.

3. System Model

We consider an LTE uplink multi-cell communication scenario made up of seven cells placed in a hexagonal grid as shown in Figure 1 with only two cells represented for illustration purpose. Each cell comprises an LTE BS and M2M devices in clusters. As shown in the figure 1, the base stations are located at the center of the cells. M2M devices designated as cluster heads (gateways) are first distributed randomly in the hexagonal shapes of the multicellular system. Then M2M devices designated as cluster members are distributed randomly around the cluster heads utilizing a PPP with density lambda (λ). One drawback in clustering this way is the excess energy consumption imposed on the cluster head. This constraint can be solved by either rotating the role of acting as cluster head among members of the cluster or by employing designated cluster heads that are not energy-limited with a higher energy as considered in this work.

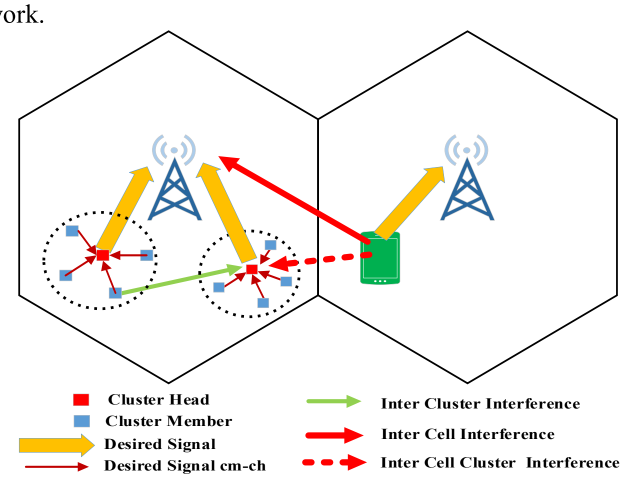

Figure. 1. System model

The cluster heads are thus located at the centre of the clusters with radius R_c. The average number (n) of M2M devices in a cluster is therefore calculated as:

$$n = \lambda\pi \, {R_c}^2 \qquad (1)$$

Each cluster member communicates with the base station through its cluster head. The wireless propagation between the cluster members and the cluster head, and between cluster heads and base station is characterized by a short distance propagation model and long distance propagation models respectively [13]. In this work, we investigate the performance of M2M transmissions in the center cell, accounting for out of cell interference caused by the other cells. We assume that there is no intra-cell interference, since all transmissions within a cell are scheduled orthogonally by the base station.

The SINRs for the cluster members to the cluster heads and the cluster heads to base station connection are determined by the geometric distances according to the selected path loss models. We assume that the base station has channel state information (SINR) about the cluster head connections and the cluster heads have channel state information about the cluster member connections. From [24], SINR would be a better measure for the working point than the SNR because at low SNR the power of the interfering signals is negligible compared to the noise level and at high SNR, the interference is dominant. For a cluster head h receiving data from a cluster member m, the SINR is given by:

$$SINR_{mh} = \frac{P_{rx,h}}{\sum_{k=1}^{K} P_k + N_o} \qquad (2)$$

Here, $P_{rx,h}$ is the received power at the cluster head, P_k the interference caused by user k at the cluster head position, K the total number of interferes at the cluster head and N_0 the corresponding thermal noise power. Similarly, for base station b receiving data from cluster head h, the SINR is given by:

$$SINR_{hb} = \frac{P_{rx,b}}{\sum_{i=1}^{I} P_i + N_0} \qquad (3)$$

where $P_{rx,b}$ is the received power at the base station, P_i the interference caused by cluster head i at the base station, I the total number of interferes at the base station and N_0 the thermal noise power. Applying Shannon's capacity formula, the resulting data rate (in bits per second) for cluster member-to-cluster head and cluster head-to-base station communications are given in Equations (4) and (5), respectively, where B_{mh} and B_{hb} are the respective bandwidth allocations.

$$R_{mh} = B_{mh} log_2(1 + SINR_{mh}) \qquad (4)$$

$$R_{hb} = B_{hb} log_2(1 + SINR_{hb}) \qquad (5)$$

3.1 Uplink Scheduling Algorithm

The task of the uplink scheduler is to decide upon the number of allocated Physical Resource Blocks (PRBs), their location, their Modulation and Coding Scheme (MCS), and the power with which each UE with traffic (be it data or control) is going to transmit. The three basic scheduling algorithms considered in this performance study of energy consumption are **Round Robin (RR), Max Throughput (MT) and Proportional Fair (PF).**

The **RR** scheduler delivers fairness for all users allocating the same number of resource blocks (RBs) for each user in an ordered manner with the same priority. This priority to fairness disregards system throughput and thus achieves the lowest value.

The **MT** scheduler allocates a different number of RBs for each user derived from the channel quality, SINR to maximize the average system throughput. It prioritizes users having the best channel conditions (i.e., with higher SINR) and hence does not schedule those users experiencing severe channel fading. This feature allows it to provide a higher capacity and throughput as compared to the other schedulers. At time *t*, the MT scheduler is given as:

$$j = arg \max_i \left(R_{i,n}(t)\right) \qquad (6)$$

$R_{i,n}(t)$ is the instantaneous data rate experienced by user i for the resource block *n* provided the user's data packet buffer is non empty; otherwise, the user is not served.

The **PF** scheduling algorithm assigns the PRBs to the user equipment with the best relative channel quality. Its main goal is to achieve a balance between maximizing cell throughput and fairness. The scheduling algorithm keeps track of the average throughput of each user in a past window of length t_c. User *i* selected to be served in scheduling slot *t* is given in [25] as:

$$i = arg \max_k \frac{R_{k,n}(t)}{T_{k,n}(t)} \qquad (7)$$

$R_{k,n}(t)$ is the estimation of the supported data rate of user *k* for the resource block *n* and $T_{k,n}(t)$ is the average data rate of terminal *k* over a window in the past. The average throughput is calculated by using the exponential weighted moving average of the instantaneous data rate as:

$$T_{k,n}(t+1) = \begin{cases} \left(1 - \frac{1}{t_c}\right) T_{k,n}(t) + \frac{1}{t_c} R_{k,n}(t) & if\ user\ k\ is\ selected \\ \left(1 - \frac{1}{t_c}\right) T_{k,n}(t) & if\ user\ k\ is\ not\ selected \end{cases} \qquad (8)$$

It is known in literature that the maximum achievable throughput can be predicted by Shannon's capacity formula. The expected achievable throughput $T_i(t)$ for i between cluster members and cluster heads and that between cluster heads and the base station is thus calculated using equations (4) and (5) for the implementation of the respective PF scheduling.

3.2 Channel Model

The wireless channel is generally known to be prone to different types of fading sources between nodes in communication systems. In this work, Rayleigh fading is considered for the channel between both the cluster member to cluster head (cm-ch) communication and cluster head to base station (ch-bs) communication. The macroscopic path loss of cm-ch and ch-bs connections is modelled by 3GPP 3D-UMi and 3D-UMa model, respectively as provided in [26]. The NLOS for the UMi and UMa is applied for both, cm-ch and ch-bs communications because of the assumption of the urban environment which experiences strong non-line-of sight (NLOS) condition due to a high density of obstacles availability, which obstruct radio signals in the propagation path.

3.3 Energy Efficiency Computation

Energy efficiency is defined as the number of information bits transmitted per unit energy. Among the components that contribute to the energy consumption in wireless communications, the communication part is documented in literature as the dominant one. The energy efficiency (E) of the n^{th} user at time *t*, is thus given as:

$$E_n(t) = \frac{R_n(t)}{P_c + P_n(t)} \tag{10}$$

where R_n and P_n is the data rate and power consumption of the n^{th} user respectively. Here, P_n is equal to P_m or P_h (depending on cluster member or cluster head) if the device transmits; otherwise it is zero. Furthermore, P_c is the circuit power for powering the device (e.g. for signal processing and amplification) and is considered as a constant value.

4. Results and Discussions

The system parameters to simulate the scenario for the performance evaluation are presented in Table 1.

Table 1. Simulation Parameters

Parameter	Settings
Cell Radius	500m
Cluster Radius (Rc)	50m
Path loss ch-bs	3D-UMa
Path loss cm-ch	3D-UMi
cm-ch bandwidth (B_{mh})	120kHz
ch-bs bandwidth (B_{hb})	1280kHz
Circuit Power (Pc)	3.2mW
Cluster member transmit power (Pm)	0.01W
Cluster head transmit power (Ph)	0.3W
H2H equipment transmit power (Pue)	1W
Thermal Noise Power	No= -174+10*log10(B)+F
M2M Application	Smart Meter
Packet size	10000 bits

The values for Pc, Pm and Ph in table 1 are taken from [13]. F in table 1 is the noise figure of value 9dB. Each device generates 10 packets, each containing 1000 bits at random time instances making up the 10000 bits provided in table 1. The ch-bs bandwidth allocation is bigger than that of the cm-ch because comparatively, large amounts of data have to be transmitted on the link from the cluster head to the base station. M2M devices placed in a circle with radius 50m are created following a PPP with density lambda, 0.010. This area and this density yield 68 M2M devices on average in a cluster. 20 clusters are simulated using Matlab. Considering uplink transmissions, the performance evaluation is done to compare the energy efficiency of the three scheduling algorithms, RR, MT and PF using empirical cumulative distribution function (ECDF) for visualisation. The ECDF of the M2M device energy efficiency performance for the cluster member to cluster head communication and cluster head to base station communication are shown in Figures 2 and Figure 3, respectively.

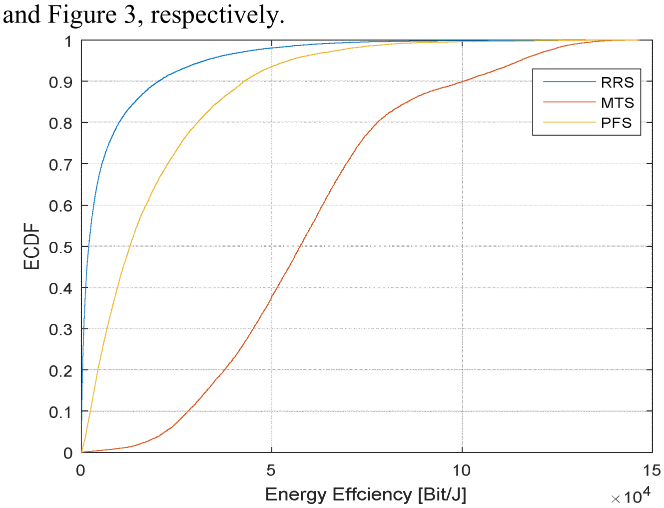

Figure. 2. Energy Efficiency cm-ch Communication.

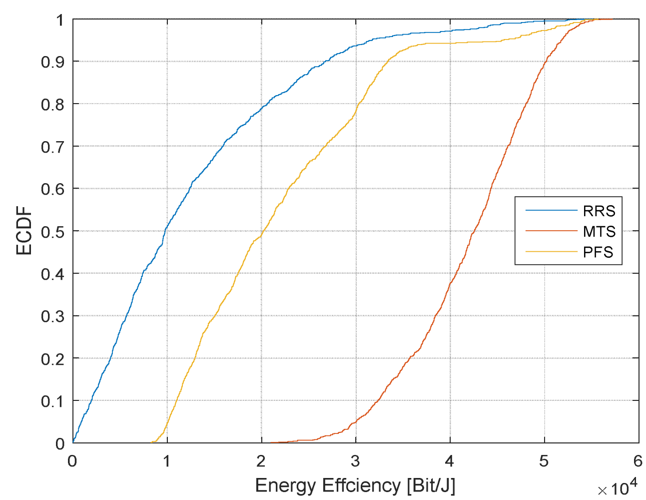

Figure 3: Energy Efficiency ch-bs Communication.

The figures show the bit per joule received by the cluster heads from the cluster members and that received by the base station from the cluster heads respectively. From these results, it can be seen that the MTS achieves the best energy efficiency followed by the PFS and the RRS. It must however be noted that even though the MTS performs better, only the devices with the best channel condition transmit packets ignoring those with poor channel conditions. It is thus not fair to all devices. MTS thus trades fairness for energy efficiency. This implies on the other hand that the latency of MTS is a lot better than the other two schemes since the packet buffer is likely be a lot smaller. It is also important to know that the energy efficiencies shown in figures 2 and 3 only account for time instances when a cm or ch was active. This means that if a cm or ch has nothing to transmit at a given time instant, the energy efficiency for this cm or ch at this time instant is not calculated. This behaviour is a characteristic of the finite traffic model employed in this simulation.

The behavior of the energy efficiency performance of the algorithms corresponds to the SINR for cluster member to cluster head and cluster head to base station communications as shown Figures 4 and 5 respectively.

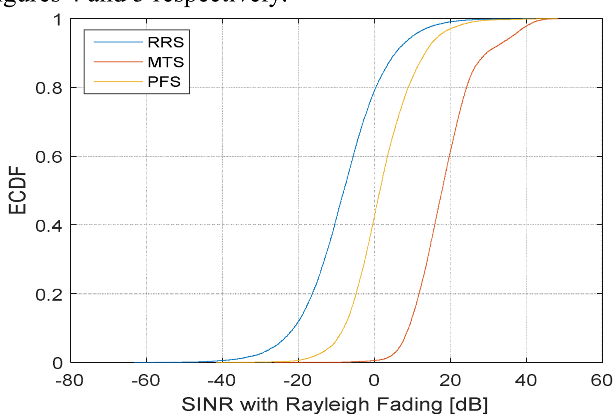

Figure. 4. ECDF of cm-ch SINR

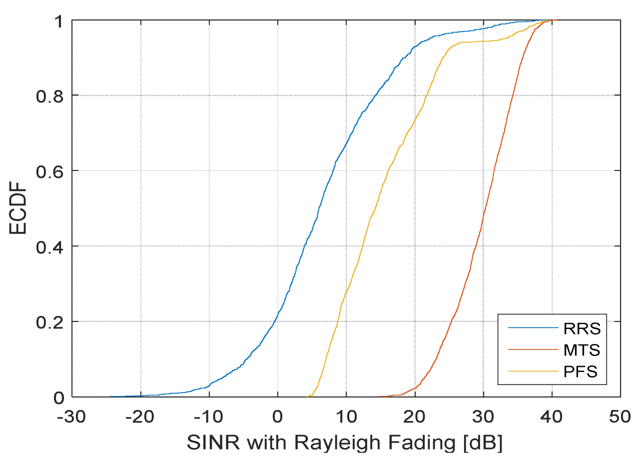

Figure. 5. ECDF of ch-bs SINR.

The results show that MTS always has the strongest SINR because it gives priority to devices with better channel conditions to transmit leaving those with weak channel conditions in starvation. RRS displays the worst SINR behaviour because it allocates resources fairly to all devices regardless of their channel conditions, making it the least energy efficient among the three algorithms. Because the PFS assigns PRBs to the user equipment with the best relative channel quality by keeping track of the average throughput of each user in a past window, its performance is seen as a balance between RRS and MTS.

5. Conclusion

In this paper, a performance analysis of energy efficient scheduling in the uplink for M2M communications is presented. The considered scheduling algorithms are round robin, maximum throughput and proportional fair scheduling. A clustering technique to address the problem of massive access and the associated energy constraint in communicating directly to the base station was employed. Clustering technique solves this problem by using the cluster members to aggregate their data at the cluster heads (gateway) which in turn transmits them to the base station. Our results indicate that the max throughput algorithm is the most energy efficient followed by the proportional fair algorithm and the round robin scheduling. However, the max throughput algorithm trades fairness for energy efficiency, the proportional fair algorithm achieves a balance between maximizing energy efficiency and fairness while the round robin scheduler is the most fair.

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