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Research Article

Service Time-Based Region Division in OVSF-Based Wireless Networks with Adaptive LTE-M Network for Machine to Machine Communications

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The 3GPP standards have presented the LTE-M as one of the main technologies to provide services to Internet of Things (IoT). The IoT applications are usually short-lived applications like smart sensing, surveillance systems for home or businesses, and data uploading applications like metering. In this paper, the proposed architecture of the base station has a LTE interface which assigns resource blocks (RBs) and another 3G interface which is equipped with orthogonal variable spreading factor (OVSF) codes. The IoT devices deployed ubiquitously leads to massive machine type communication, which leads to burst traffic on current cellular services. The IoT devices when assigned large resources will reduce the radio efficiency. The work in this paper assigns OVSF codes available on 3G interface to the IoT devices. The LTE resources are used for IoT devices in case of emergency or when resources of 3G interface are 100% utilized. This will solve the problem of both small data transfer and connectivity requirement of IoT devices. The IoT applications are event-driven and time-bound also, and the resources are also reserved for these applications in the proposed work. The simulations and results show that proposed work increases both network efficiency and capacity.

1. Introduction

In *Internet of Things (IoT)* devices are connected to each other physically. IoT provides services like disaster detection, e-health, surveillance of places, grids, etc., which makes life convenient. The IoT is basically a machine-to-machine (M2M) communication; this made machine to machine (M2M) communication an attractive technology for industry and researchers. It is a novel communication technology in which large number of wirelessly connected devices can share information with each other. By 2021, 15 billion devices are expected to be connected using M2M communications as predicted by Ericsson [1]. The large number of devices and other connectivity issues challenges imposed on cellular networks will be addressed by 3GPP standards. Some of challenges are reducing latency, reducing device cost, and increasing support to large number of devices, extended with enhanced coverage [2–4].

Although small-size packets are transmitted by devices using M2M communication in time intervals, their specifications and functions create synchronized storms of payload as compared to traditional cellular communications. This will lead to saturation of the limited bandwidth of the LTE-M without 3G interface with increased number of devices. This problem will become more prominent in the conditions of emergency (floods, terrorist attacks, fire, etc.) when all the devices connected to critical services want to send their data simultaneously. This will basically lead to blocking of either cellular communication or M2M communication, which degrades further when additional devices join the network due to the random nature of devices joining and leaving the network [5].

The LTE-M assigns a resource block (RB), which can transmit hundreds of data bits at a time. On the other hand, the IoT applications require small data to be transmitted at a time, as they are mostly event based. The assignment of a RB to IoT applications will severely reduce efficiency of the network as a whole and will lead to blocking of cellular calls. The M2M calls carry small data with required quality of service (QoS).

In order to address these problems, the IoT calls are mostly handled using 3G interface and cellular calls using LTE-M interface in this paper. The proposed solution will use the available 3G interface in the base stations (BSs) which is mostly used for voice calls in cellular communications. There is only topological difference in which M2M devices are connected in this paper, and they are connected to a gateway and can also communicate directly with the BS. The remaining topology of the M2M network is similar to topology available in literature like transmission data can be aggregated on one device from multiple devices and that device is a gateway for those devices. The proposed topology uses OVSF codes as resources for handling IoT calls; LTE-M resources are used in case of emergency and during nonbusy hours of cellular communication. In this paper, a new service time-based region division of OVSF code tree is used which is best suited for IoT applications like metering information of grid, surveillance information periodic update, etc., the IoT calls for which data is known in advance. This will further improve the resource efficiency. The OVSF code tree is divided based on service time required which will reduce latency and provide better QoS. The overall network efficiency will also increase.

The rest of the paper is organized as follows. The literature survey of the related work is done in Section 2. In Section 3, the network architecture and problem is defined. In Section 4, the proposed scheme is discussed and used for handling IoT calls. Simulation and results are presented in Section 5. The paper is concluded in Section 6.

2. Related Work

In the literature, the work done is focused on coverage, capacity, and emergency services using LTE-M and/or narrow band IoT. The work in [6] has examined the platforms for providing M2M service and explored the problems which might appear while handling M2M services. The work in [7] focuses on resource allocation in both spatial and temporal manners. The network performance is improved in [8–11] using path selection strategies. In [8], the path is selected on the basis of channel conditions, this improves throughput as the path with best channel conditions reduces loss of information. The work in [9] imposed the devices to form connection with the nearest gateways in order to improve transmission quality. The scheme in [10] decides the path depending upon the received channel quality while accommodating both parameters efficiency and resource utilization. The devices in [11] choose their gateways based upon transmission time, which improves the transmission efficiency. All these suffer from wastage of radio resource as individually connected devices lead to blocking of resources. This problem is solved by sharing the physical resource blocks between devices in [12].

The work is also done for efficient utilization of RBs in eNodeB; in [13], the number of devices that can be handled by eNodeB are increased using a cross-layer approach. The TCP/IP overheads are reduced by clustering and buffering. Using this approach, eNodeB can handle up to 65 K devices at a time for a 10 MHz bandwidth case. However, it affects QoS of both M2M and cellular communication in congestion state. A source modelling approach which is based on Coupled Markov Modulated Poisson Processes (CMMPP) is proposed in [14], to handle massive devices and problems associated with them. It proposes the parallel implementation of 30 K M2M devices. A mathematical model was proposed in [15], for LTE downlink bandwidth assignment to improve QoS for the devices; the bandwidth adaptation was not discussed while proposed with the aim of providing a good QoS for each UE; the coexistence between LTE-M and LTE-A systems and the bandwidth adaptation are not spotted. The work in [16] uses a cognitive radio-based access approach which works on both the priority and queuing. The M2M devices are differentiated on the basis of their QoS requirements.

Most of the work in the literature uses LTE bandwidth for M2M communication. No work is available in the literature which uses already available 3G interface at the BS. This interface can be used to provide faster access to the M2M devices without creating much interference. This interface can also handle mission critical cellular calls in case of emergency.

3. Network Architecture

The network architecture is introduced in this section for both M2M devices and cellular communication. The eNodeB has an LTE interface which assigns RB(s) and a 3G interface which assigns OVSF codes. The network is assumed to have one eNodeB, a group of nests are connected to it. In this section, the network architecture of LTE-M is first defined. Then, the traffic features and QoS requirements of the M2M devices are described. The 3 G interface is equipped with OVSF code tree of 9 layers.

3.1. LTE-M Network Architecture. In the LTE-M network, for communication, two types of machines are involved, M2M devices and M2M gateway. The M2M devices considered in this paper are consumer devices which enable communication and can communicate directly with eNodeB or connect to gateways using two hop communication. The gateways improve the transmission efficiency as they help devices to transfer data to eNodeB. This formation of nesting and gateway is based on distance; the gateways are the devices which are closer to eNodeB and provide connection to the devices in the nest eNodeB. The gateways can be dynamic or static depending upon there mobility. The device can join and leave a nest dynamically. The LTE-M network architecture with cellular users is shown in Figure 1.

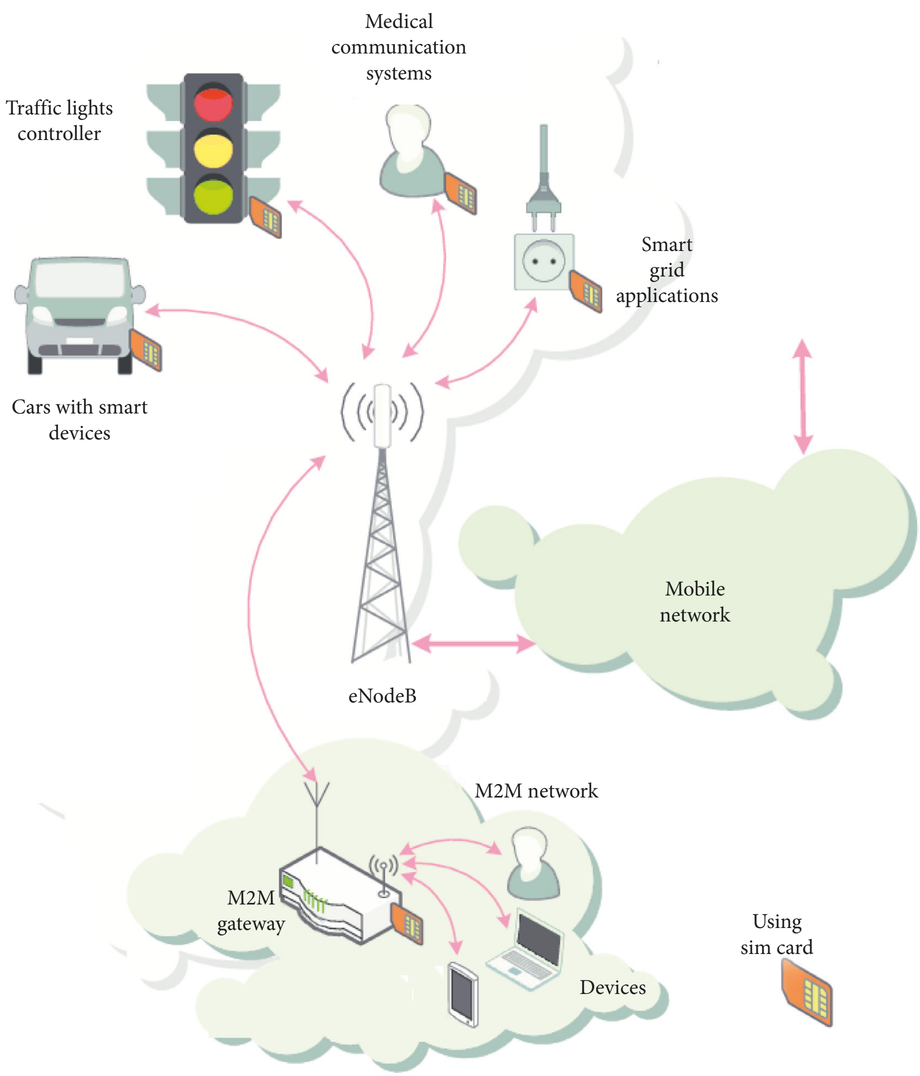

FIGURE 1: Smart communication system with M2M network, smart grids, and possible cellular communications.

3.2. Traffic Type and QoS Requirements. The IoT applications generate broadly three types of traffics, depending upon the type of the QoS and delay requirements: the delay-tolerant traffic with constant bandwidth requirement, delay-tolerant traffic with flexible bandwidth requirement, and delay-sensitive traffic with fixed bandwidth requirements. The cellular communication is divided into two categories: delay-tolerant with flexible bandwidth and delay-sensitive with constant bandwidth requirements (voice calls). The LTE resources will mainly be assigned to cellular communication for calls requesting delay tolerant with flexible bandwidth. The OVSF codes in two dimensions are used for assignment to handle any type of calls when LTE resources are busy. A minimum of two time consecutive RBs are assigned to a device (cellular or M2M) and contingent on utilized modulation and coding scheme (MCS), the device transmits between 32 and 616 bits/subframe when using LTE interface.

The M2M gateway collects payloads from all the devices connected to it, when LTE resources are busy and transmits when they become available. The M2M gateways are mostly used when M2M devices cannot communicate directly with eNodeB or when no vacant code is available for assignment in OVSF code tree. This leads to reduction in the wastage of RBs, especially when devices have less bits to send.

4. Network Parameters and Properties

In LTE, resources are divided into time and frequency. In time domain, the radio frame used is of 10 ms, which is further divided into 10 subframes of 1 ms as shown in Figure 2 [17]. A subframe is divided into two slots of 0.5 ms. Each slot is of 6 or 7 orthogonal frequency division multiple access (OFDMA) symbols. In frequency domain, the smallest unit is of 15 KHz which is termed as resource element (RE). A resource block constitutes 12 subcarriers which is a duration of one slot and total bandwidth 180 KHz.

In this paper, the uplink transmission for an eNodeB is considered for d_i, M2M devices where $1 \le i \le m$, and g_j, M2M gateways where $1 \le j \le n$. These M2M devices can communicate directly with eNodeB and can communicate through M2M in a two-hop manner. The M2M devices

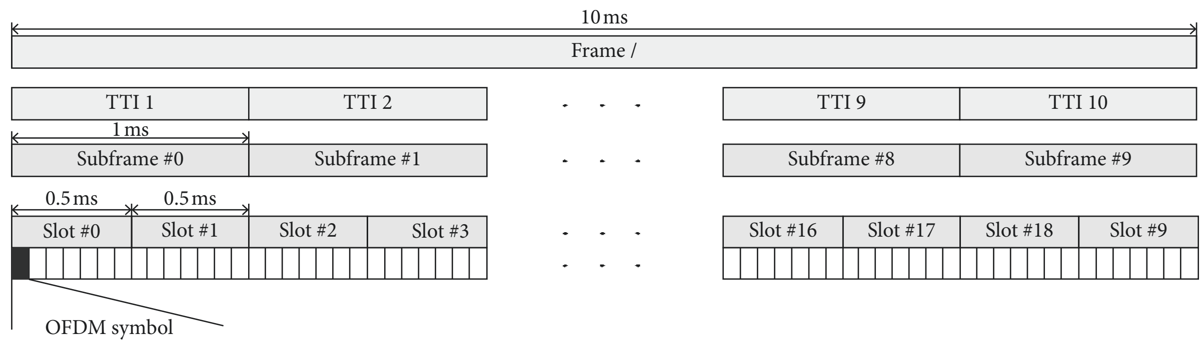

Figure 2: An LTE PHY frame structure.

decide the communication they will use depending upon status of eNodeB and their distance from the eNodeB. Usually, the M2M devices at the boundaries of coverage area use two-hop communication or when amount of information is less. When eNodeB capacity is fully utilized, then also the two-hop communication is utilized by M2M devices through M2M gateways. The M2M gateways are also equipped with storage capacity. They can store the information received from M2M devices. The M2M gateways transfer their data depending on the location from eNodeB while using 3G interface and using a suitable AMC scheme given in Table 1.

The 3G interface uses 2-dimensional OVSF codes to handle cellular voice calls and M2M calls. The system model in this section describes the notations used, identification of codes, and formulae used to find *Cl* of a time domain code.

A binary tree is used to generate an OVSF code tree of l layers where $l \in [1, L]$, L is the root layer [9]. A channelization code used for assignment on 3G interface is represented by C_{l,n_l}, where n_l is its position in layer l and $n_l \in [1, 2^{L-l}]$. A code in any layer l has spreading factor $(\mathrm{SF}) = 2^{L-l}$. The codes in the lowest layer 1 has a maximum spreading factor of 2^{L-1}. The higher the SF of a code, the lower the rate supported by it and vice versa. The OVSF codes support quantized rates of the form 2^{l-1}. The orthogonal nature of the codes leads to the problem of code blocking, which prevents assignment of codes in layers below and above an assigned code. This leads to fragmentation of available radio resources in the code tree and can be reduced by using careful assignment schemes. The OVSF codes in this paper spreads in both time and frequency domain. The code in time domain is denoted as $C_{2^{l_t-1},n_{l_t}}$ and as $C_{2^{l_f-1},n_{l_f}}$ in frequency domain [18]. The code spreads in 2 dimensions retains the orthogonal nature. The channelization code, time domain code, and frequency spreading code SF are related to each other by

$$2^{L-l} = 2^{k_t-1} \times 2^{k_f-1}, \quad (1)$$

where k_t and k_f denotes the index levels for time and frequency domains codes, which are related to each other as

$$L - l = (k_t + k_f - 2), \quad (2)$$

and the code indexes n_l, n_{l_t} and n_{l_f} are related by

Table 1: Relation between MCS index, modulation, and TBS index.

MCS index	Modulation	TBS index
0–9	QPSK	0–9
10–16	16QAM	9–15
17–28	64QAM	15–26
29	QPSK	
30	16QAM	Reserved
31	64QAM	

TBS: transport block size.

$$n_l = n_{l_f} + \left(n_{l_t} - 1\right) \times 2^{k_f-1}. \quad (3)$$

5. The Proposed Scheme

The proposed scheme is explained in this section. The eNodeB is equipped with two gateways LTE and 3G. The RBs are assigned when LTE interface is used and OVSF codes are assigned when the 3G interface is used. The main idea of the work is to maximize the utilization of RBs and existing resources in the 3G interface without affecting QoS.

The calls which can be arrived or generated in the network are as follows:

(a) Cellular calls for cellular devices: Type-I

(b) Cellular data calls: Type-II

(c) M2M gateway to eNodeB: Type-III

(d) M2M device to M2M gateway: Type-IV

Generate a call of rate qR. The algorithm for all types of calls works as follows.

Case 1. $qR \in \text{Type}-\text{I}$. These calls are voice calls which are handled using 3G interface. The service time of these calls or average call durations are usually less than 2 minutes. Assign the OVSF codes from the 3G interface using service time-based division (STBD) assignment scheme explained in Section 5.1.

Case 2. $qR \in \text{Type}-\text{II}$. These calls are data calls and are handled using LTE interface. Assign required number of RBs using LTE assignment scheme proposed in Section 5.2.

Case 3. $qR \in$ Type − III. The algorithm will check the available resources of LTE interface 1st, and if LTE interface available resources are not enough, 3G interface will be used to handle the call.

Case 4. $qR \in$ Type − IV. The algorithm will check the amount of data required to transfer. For small data transfer request, the 3G interface will be used, and for large data transfer request, the LTE interface will be used. Also, availability of LTE interface will be checked, in case where LTE resources are busy, and 3G interface will handle the call at a slower speed.

5.1. Service Time-Based Division. For a call of rate qR, the improved service time-based division (STBD) scheme will determine the value of $u = \log_2 q + 1$ [18]. The STBD scheme considers the U number of user classes with rates $2^{u-1}R, u \in [1, U]$. The STBD scheme divides the code tree into U regions, and available capacity of each region is limited by channel load of that region.

The capacity of the tree and number of classes can have these possibilities:

(i) For $i = 0$.

(ii) If $(2^{L-1}/U) \in I$ and $2^{U-1} \leq (2^{L-1}/U)$. The allocated capacity to each class will be $(2^{L-1}/U)R$.

(iii) If $(2^{L-1}/U) \in I$ and $2^{U-1} > (2^{L-1}/U)$. Increment $i = i + 1$, the capacity allocated for class U is $2^{U-i}R$. The total unused capacity is $(2^{L-1} - 2^{U-i})R$.

(iv) If $(2^{L-1}/U) \notin I$. Increment $i = i + 1$ and set $(2^{L-1}/U) - (2^{L-1}/U) = A$. If $A > (1/2)$, set $B = (2^{L-1}/U)$, else $B = (2^{L-1}/U)$. Find $n_i = \max[n_i']$, $n_i' \geq 0$, $\exists n_i \times 2^{U-1} \leq B$. There are three possibilities as follows:

  (a) If n_i is zero, the capacity assigned to U class is $2^{U-1}R$. For finding the capacity of classes $(U - 1)$ to 1 replacing $(2^{L-1}/U)$ with $(2^{L-1} - 2^{U-i})/(U - 1)$ and U with $(U - 1)$, respectively, in step (i) and proceed.

  (b) If $n_i \neq 0$, and $(n_i + 1) \times 2^{U-i} - B \leq 2^{U-(i+1)}$ the capacity allocated to U class is

$$C_{\max}^{L'} = (n_i + 1) \times 2^{U-i}, \quad (4)$$

$$C_{\max}^{U-i+1} = n_i \times 2^{U-i}R. \quad (5)$$

  (c) If $n_i \neq 0$, and $(n_i + 1) \times (2^{U-i} - B) > 2^{U-(i+1)}$, the capacity allocated to class $(U - i + 1)$ in the first round $(U - i + 1 = U)$ is given by

The capacity to be distributed in remaining $(U - i)$ classes is given by

$$\sum_{p=1}^{U-(i+1)} C_{\max}^{p} = 2^{L-1}R - C_{\max}^{U-i}. \quad (6)$$

For the capacity of remaining classes, steps (i)–(iii) are repeated and replace $(2^{L-1}/U)$ by $(2^{L-1} - 2^{U-i})/(L - i)$ and U with $(U - 1)$. For example, for the code tree with capacity $32R$ and number of user classes 4. The capacity allocated to class 4 users is $16R$, and for the classes 1 to 3, the remaining capacity $16R$ will be distributed. The capacity distribution algorithm will start from Step (i).

Let the average service time for class u user is $t_{s,u}$, where $1 \leq u \leq U$. The U regions are arranged in the ascending order of the average service time. Let the service time required by the ith call is t_i^s and elapsed time of ith call at a particular time is denoted by t_i^e. Let a new call (say ith call) with rate $2^{l-1}R$ wants a vacant code. The call is given the vacant code from the region l that is dedicated to $2^{l-1}R$ calls. The total service time for ith call can have the following possible values.

(i) If the service time for ith call with rate $2^{l-1}R$ has a value less than or equal to $t_{s,u}$, the call will stay with code in region u till completion.

(ii) If the service time for ith call with rate $2^{l-1}R$ has value greater than $t_{s,u}$, when the elapsed time t_i^e of the call exceeds the average service time of the uth region, the call is shifted to region (u-1) if the vacant code is available. If the total elapsed time for this ith call exceed $t_{s,u} + t_{s,u-1}$, the call is again shifted to region (u-2). Shifting is done to place ith call to the region in which early call completion chances are more. Doing this, it becomes certain that the existing vacant codes in the region can handle next calls that are assigned to the codes which becomes free for almost similar times.

The codes in each region are spread in 2D to improve QoS; however, it limits the number of users a region can handle. The different AMC scheme increases the number of bits transmitted.

The channel load (CL) of the region u is calculated before a new call is assigned to a region [19], if the $CL_u < CL_{Threshold}$, the call will be assigned in region u. Otherwise, check remaining regions with $CL < CL_{Threshold}$. The call will be assigned in the available region. The Type-I calls are always handled using 3G interface.

5.2. LTE Scheme. The LTE resources are assigned based on the priority Type-II > Type-III > Type-IV calls. The Type-II calls are further categorized as emergency M2M calls and cellular data calls. The former has a higher priority. These are top priority calls and are handled using LTE resources; the legacy 3G network will lead to latency. The LTE-M devices in this paper are without carrier aggregation (CA) capability. They can only use one component carrier (CC) at a time.

Consider a LTE-M network system channel bandwidth 20 MHz at 2 GHz frequency. The used AMC schemes are QPSK, 16QAM, and 64QAM. The total number of RBs, the used RBs, and the required RBs for new call are denoted as RB_T, RB_u, and RB_r, respectively. For a call of rate qR, determine the required number of RBs.

For a Type-II call with a flag of emergency, the algorithm works as follows:

(a) If $RB_r \leq (RB_T - RB_u)$

Assign required RBs to the M2M device and update $RB_u = RB_u + RB_r$.

(b) Else if

Find the M2M device using the number of $RBs = RB_r - (RB_T - RB_u)$, switch the M2M device call to 3G interface and handle Type-II call with a flag using $(RB_T - RB_u)$ and RBs of this call.

(c) Else

Find the M2M device using the number of $RBs = RB_r$, switch the M2M device call to 3G interface, and handle Type-II call using RBs of this call.

(d) End

For all other calls Type-II-IV. The priority of calls is Type-II > Type-III > Type-IV. For a new call with required number of RBs as RB_r. The algorithm works as follows.

(a) If $RB_r \leq (RB_T - RB_u)$

Assign required RBs to the cellular device and update $RB_u = RB_u + RB_r$ which are of good channel quality (CQ) for cellular device.

(b) Else if

Find the M2M device using the number of $RBs = RB_r - (RB_T - RB_u)$ with same CQ, switch the M2M device call to 3G interface and handle Type-II cellular call using $(RB_T - RB_u)$ and RBs of this call.

(c) Else

Find the M2M device using the number of $RBs = RB_r$, switch the M2M device call to 3G interface and handle Type-II cellular call using RBs of this call.

(d) End.

For Type-III, which are usually high data calls. The algorithm works as follows.

(a) If $RB_r \leq (RB_T - RB_u)$

Assign required RBs to the M2M gateway and update $RB_u = RB_u + RB_r$ which are of good channel quality (CQ) for M2M device.

(b) Else

The M2M gateway will transfer the data to another M2M gateway with storage capability equal to data of the call, having better channel quality and is closer to eNodeB using 3G interface STBD scheme. The second M2M gateway will now generate a new call of rate including own data and data transferred to it.

(c) End.

For Type-IV, the algorithm works similar. If the required RBs are not enough to handle the new call, the M2M device will transfer its data to M2M gateway using 3G interface STBD scheme.

6. Performance Evaluation

In this section, the simulation results of the proposed STBD schemes are compared with existing schemes in literature. The channel bandwidth used is 5 MHz, 25 resource blocks are used per subframe, M2M devices varied between 1600 and 7200, and M2M gateways varied between 320 and 1500. The path loss model equation [17] between gateway and $\text{eNodeB} = 128.1 + 37.6 \log(d)$ and between device and $\text{gateway} = 48.9 + 40 \log(d)$, where d is in km. The M2M devices considered are of variable nature and different bandwidth requirements, message bits size varies between 8 and 16 [7]. The results are average of 10000 simulations. The proposed STBD scheme is compared with four schemes *spatial and temporal aggregation* (STA) [7], *direct communication* (DC) scheme and *shortest distance* (SD) [10], and the *shortest time* (ST) scheme proposed in [11]. These are among the best schemes available in the literature, which improves one parameter at the expense of the other. The STA scheme proposed in [7] uses gateways to aggregate data and outperform the remaining three schemes. The devices using DC scheme upload data to eNodeB directly, the SD scheme uses the closest gateway for a particular device, and ST uses the path which takes minimum transmission time. The schemes are compared on the performance metrics of *capacity* and *efficiency*, which include the following:

Capacity

(i) Number of served M2M connections
(ii) Throughput

Efficiency

(i) Data bits transmitted
(ii) Number of RBs allocated

6.1. Capacity.

In Figure 3, the number of requests of devices are compared with number of served requests. The STBD scheme services maximum requested connections as it uses OVSF codes on 3G interface to handle devices for direct communication and in conditions when 4G interface resources are fully utilized. The STBD scheme can accommodate more M2M devices when cellular traffic is less. The throughput of all the schemes are compared in Figure 4, the throughput of STBD scheme is comparable to STA scheme which outperforms other scheme as it effectively aggregates small data. The STBD scheme uses different AMC schemes to improve throughput in case when devices are at longer distance for improving link quality when using OVSF codes. It also uses M2M gateways when device cannot communicate directly using 3G or 4G interface.

6.2. Efficiency.

In Figure 5, the number of data bits transmitted is compared with number of devices request. The efficiency of data bits transmitted of all schemes increases with number of devices except DC, as direct communication link quality decreases with distance. The number of data bits transmitted for STBD scheme is significantly higher than other schemes as it uses OVSF codes to provide services to

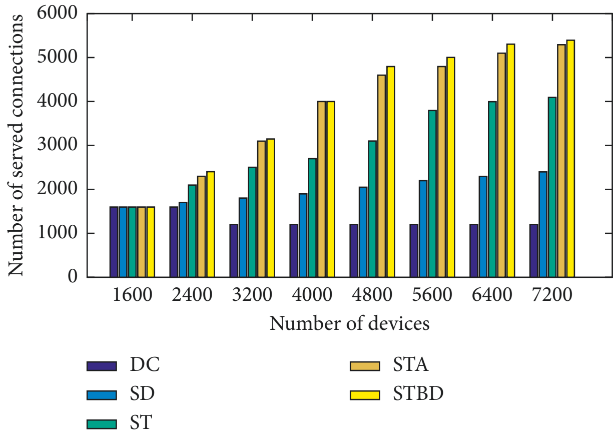

Figure 3: Number of requests from devices compared with number of served requests.

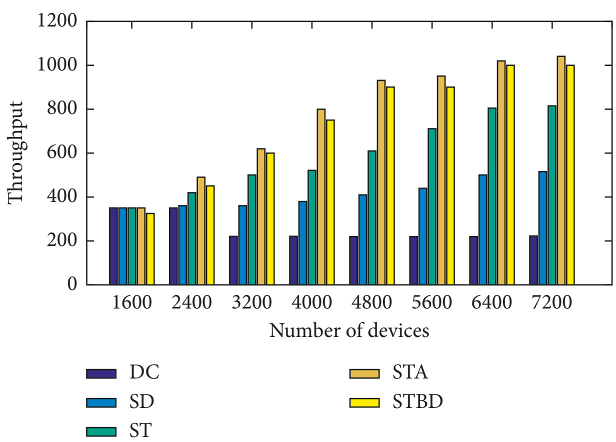

Figure 4: Throughput of the system.

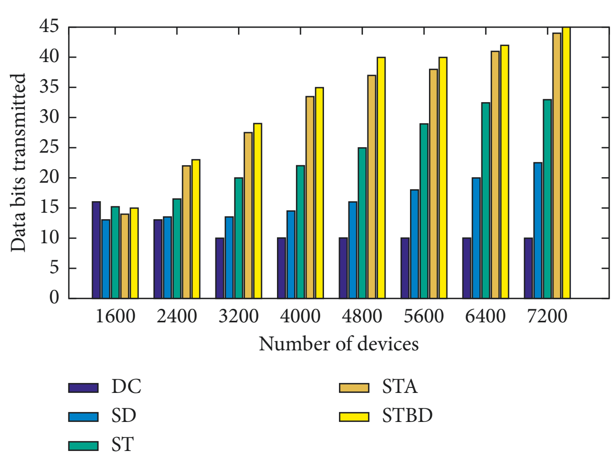

Figure 5: Number of requests from devices compared with number of served requests.

M2M devices in absence of 4G interface resources. The OVSF codes uses different AMC scheme to counter the effect of distance.

In Figure 6, the number of RBs allocated per second is compared. The STBD scheme outperforms all the schemes.

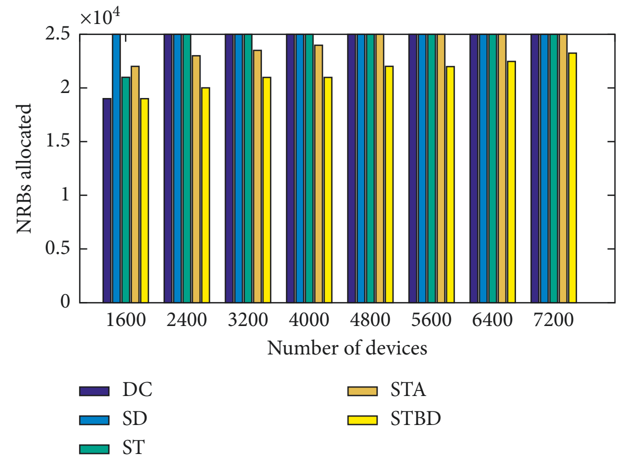

Figure 6: Number of requests from devices compared with number of RBs allocated per second.

The other scheme allocates RBs as resources while STBD scheme uses both RBs and OVSF codes. However, due to this, the throughput of the STBD scheme as shown in Figure 4 is lesser than other schemes for smaller number of devices with better system utilization.

The throughput of STA scheme is higher than the STBD scheme at the expense of utilization of higher number of NRBs, which leads to blocking of future request. The STBD scheme is the optimal scheme which provides better throughput while utilizing minimum NRB, as it uses OVSF codes. The percentage difference between NRB utilized by STBD scheme and STA scheme is around 16%. The remaining NRBs can be used to handle more number of devices while keeping the same throughput.

7. Conclusion

The research on M2M communications is ongoing where machines can communicate directly or using eNodeB. The M2M devices produce huge amount of traffic, and handling the communication of these devices using LTE resources is not possible. In this paper, a 3G interface is used to handle the communication of these devices most of the time, which leads to considerable reduction in utilization of RBs for M2M devices. The STBD scheme handles more number of devices as compare to other schemes. The spectral utilization of 3G resources is improved, and 4G resources can be used for future requests. This improved overall performance and efficiency of the used eNodeB. The M2M gateways are also used when eNodeB resources are utilized. In future, work can be done to transfer dynamically the calls between 3G and 4G interfaces.

Data Availability

The data of the research are still in use for the researchers, and releasing data at this stage might result in utilization of data for research purpose by others. The sharing of data resources is limited by researchers involved.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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