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Machine-to-machine and cell-to-cell traffic handling using relay and carrier aggregation prioritize on LTE-A PRO network

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Abstract

With the advent of artificial intelligence (AI) and smart cities, the amount of connected devices is on the rise. The communication medium perfectly suited for interconnecting all the massive machine-type communications (mMTC) is long-term evolution advanced (LTE-A). The design in this paper consists of relay stations (RSs) that are connected to the base stations (BSs). The radio access network (RAN) will consist of a base station/eNodeB (eNB) with one or two hops of RS. The machine-to-machine (M2M) communication considered here is of the type of smart meters and sensors data calls. These calls are handled according to their delay-tolerant capability. The proposed (PR-M2M) scheme assigns resources with priority without reserving the resources. The Vienna LTE Downlink level simulator is used to investigate the operation of the proposed scheme. The packet-dropping probability and average throughput of the system are simulated with other existing schemes in the studied literature. The results obtained from the simulation indicate that the PR-M2M outperformed existing schemes.

Keywords

Base station, Device-to-device, Human-to-human, Machine-to-machine, Relay station, Heterogeneous, LTE advanced.

The evolution of LTE has been steady over the last decade (5GAmericas, 2017; Kumar et al., 2019) to meet user demands, which in part are twofold-increase data utilization and second a growth in the amount of “connect devices” (Gamboa et al., 2017). The legacy mobile networks were designed to provide services to the cell-to-cell (C2C) communication that predominantly was for voice services (Teyeb et al., 2017). By the year 2022, it is predicted that there will be about 29-billion connected devices and 18 billion of those will be IoT devices or M2M devices (Teyeb et al., 2017). Currently, globally LTE has about 47% of all mobile subscribers, which include IoT subscribers. These are expected to grow by 45% in the next five years. With the continuation of LTE standard development under the guidance of 3GPP LTE, progress has been made until releases 13-14 for LTE Advanced Pro, which are networks designed with capabilities to handle machine-type communication (MTC). The MTC systems are divided into two types, massive MTC and critical MTC (Dahlman et al., 2016). The phenomenon of massive MTC, when compared to a standard mobile communication, is more on the volume of devices demanding access to resources simultaneously. This high volume of devices degrades mobile network performance. Recently, studies have been conducted on LTE-A Pro, utilizing the different enhancement features like multicarrier, multiple input multiple output (MIMO), and massive carrier aggregation to meet the demand of users (Dahlman et al., 2016; CHET, 2003; Nokia, 2015; Chao and Chiou, 2013). This contributes to the high densification of the radio-access portion due to bandwidth expansion. Therefore, another critical part of the LTE-A Pro network (Nokia, 2015) is the last-mile delivering of time-shared resources to the user’s (C2C or M2M) via packet scheduling. The most frequently used packet scheduler in implementation is proportional fair scheduler (Chao and Chiou, 2013) and at times is used as a foundation-scheduling scheme (Iru et al., 2018; Grondalen et al., 2017). The emphasis on fairness (Rostami et al., 2018; Eladham and Elshennawy, 2017) receives high attention in current research studies for C2C communication. The work in Tathe and Sharma (2019) divides resource scheduling into two types of classes: channel-dependent and channel-independent scheduling. This leads to the development of policies for scheduling whose primary purpose is to reduce complexity, which is one key principle for designing a packet-scheduling algorithm. The aim for minimizing complexity is that for each 1-ms transmission time interval (TTI) scheduling, a decision needs to be made in allocating resources and an increase in computation will increase the TTI. The work in Lassoued (2019) is based on operations of (Heterogeneous networks) HetNets, which are usually designed to deliver greater spectral efficiency and extra capacity. Therefore, they are suitable to provide coverage to a multiplicity of subscribers, including massive MTC connections due to enhanced network capacity (Hamdi et al., 2012). The work in Hamdi et al. (2012) and Cells et al. (2014) that uses relay stations for both wired and wireless media having high capacities is done for the eNB and RS interfaces. The options considered are wireless or wired with higher capacities. The design uses a wireless interface between eNB and M2M devices for communication. The implementation of the wireless interface is easy and cost-effective as it is self-optimizing. The work in this paper considers M2M communication mainly of two types of calls, which are allowed in the network, depending upon their delay-sensitive nature. The work does not reserve resources for the calls whether prioritized or nonprioritized.

The paper is organized as follows: first, the results section is presented with the discussion immediately thereafter. In the fourth section, a detailed description of Materials and methods is provided, with the fifth section describing the conclusion of the paper.

System description

The increase in massive MTC communication has contributed to new standards (Nokia, 2015; ITU, 2015; International Communication Union, 2015) being adopted for LTE, to meet the demands of (C2C/D2D) communication. As a result, numerous studies have been conducted in the recent past, exploiting different formulation models (Vardakas et al., 2015) on the performance of M2M. For the majority, simulations have been conducted in which they can represent the actual M2M/C2C traffic scenarios. However, the division of MTC into massive and critical MTC gives credence to divide M2M communication into different categories, where service classification is endorsed. The service separation assists in providing guaranteed class service to massive critical MTC communication with an acceptable QoS. A mathematical analysis is offered in the study of El Fawal et al. (2018) with a deduction that M2M/H2H traffic in emergency scenarios should not have a user's priority settings. In another research piloted in Akpakwu et al. (2017), the focus is given to the congestion-control mechanism. As can be noted, different design objectives are followed to meet the requirements of massive MTC. A fairly detailed study is presented in Grondalen et al. (2017) for diverse types of scheduling algorithms relating to the key design fundamentals. The work's main focus is presenting performance and design-scheduling algorithm comparison for user datagram protocol (UDP) and transport-control protocol (TCP) traffic. One of the main concerns for M2M network designs has to do with interference that is mitigated in the solution for HetNets (C. Telecommunications, 2015). There are also studies that focus on partial usage of the spectrum for IoT (Zhang et al., 2016) and mode selection (Sarkar et al., 2019) for HetNet (Fig. 1) toward fifth-generation networks (5G). In the study on M2M communication for Smart Grid Application (Vardakas et al., 2015; Chau et al., 2017), the authors make use of an analytic method to evaluate the performance-scheduling algorithm in comparison to simulation. Both simulation and formulation models are acceptable evaluating LTE A network behavior with regard to massive MTC. As in our study, we are utilizing the Vienna Downlink System (Vienna University of Technology (Institute of Telecommunications, 2016) simulator that is widely utilized and industry-reputable. An observation from the surveyed studies is that there are several fragmented suggestions nonexploiting.

In this paper, the proposed PR-M2M algorithm provides the priority assignment of resources to relays that form the part of the communication process. The fraction of the bandwidth is not reserved for M2M communication, depending on the user subscription profile, which is aligned with the requesting of resources as available in the literature. The proposed scheme also differentiates between M2M users based on their type: delay-tolerant and delay-sensitive.

Whereas the PR-M2M builds on existing design parameters to offer a much-improved algorithm that is advantageous to both C2C and D2D communication. The operations are conducted with

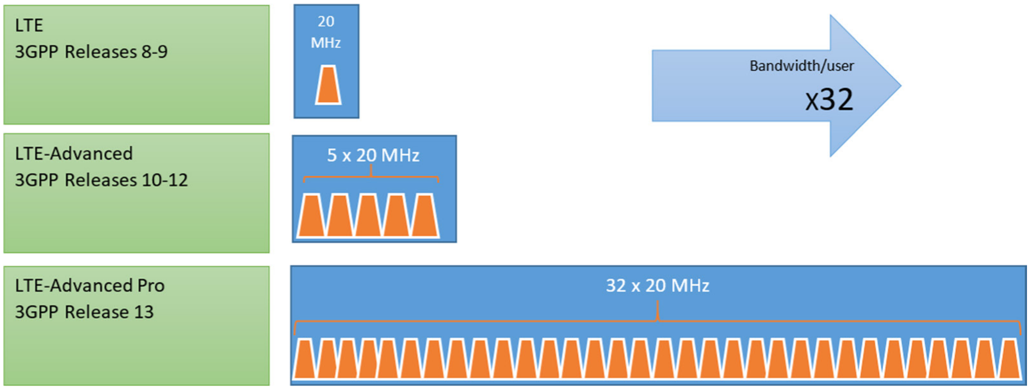

Figure 1: Carrier aggregation of up to 32 CC in LTE A PRO.

C2C communication and M2M domains. The design of a packet scheduler must adhere to certain principles (Capozzi et al., 2013) stated below:

1. Complexity and scalability
2. QoS provisioning
3. Fairness
4. Spectral efficiency

These principles are found in the PR-M2M algorithm, which is easy to design, implement, and spectral efficiency is guaranteed with the utilization of carrier aggregation as it is a fundamental aspect of LTE-A/LTE-A Pro (Grondalen et al., 2017; Haidine and El Hassani, 2017; 4G Americas, 2015; Livingston and Recchione, 2018).

Materials and methods

The network model given in Figure 2 consists of M2M devices, which directly communicate with neighboring RSs through LTE short-range (SR) links, the RSs;

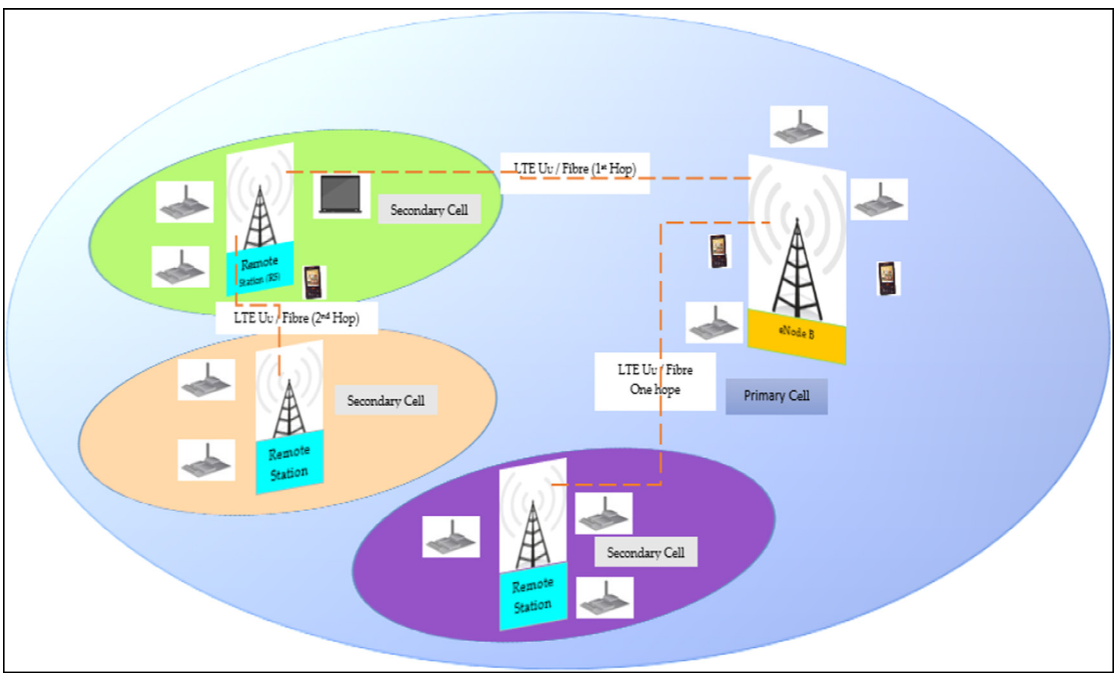

Figure 2: Heterogeneous LTE advanced network.

however, transfer the received data to the BS using the long-range (LR) LTE links. The multiple-access scheme used in the LTE downlink is orthogonal frequency-division multiple access (OFDMA). A physical (PHY) frame structure for LTE has 10 subframes in the time domain with two slots in each, 14 OFDM symbols that can be carried in each subframe. The frequency-domain subchannel has 12 carriers. The number of subchannels varied with bandwidth like each channel of capacity 1.4 MHz and has six subchannels. For a mobile station (MS) in LTE, the transmission unit is called a resource block (RB) within a subframe (in time) and a subchannel (in frequency) (Balyan and Groenewald, 2017). The scalable bandwidths are supported in LTE standards. The bandwidth and associated RBs are given in Table 1 (Balyan and Groenewald, 2017). The work in this paper assigns a fraction of available 20-MHz bandwidth for M2M-to-RS communication, RS-to-BS, and cell-to-cell (C2C) communications. The bandwidth is not blocked or reserved as done in most of the work in literature; the assigned BW to each format of communication is flexible. This is mainly due to the diverse nature of C2C communication and the introduction of data aggregation at RSs. Further, with the use of carrier aggregation (CA) for LTE-A, the available bandwidth can be extended up to five carriers, i.e. 100 MHz.

Channel model

The channel gain on the communication link between any two nodes denoted by *i* and *j* using a subcarrier *k* is

$$G_{i,j,k}dB = -\left(\lambda log d_{i,j} + \kappa + \beta_{i,j,k}\right) + 10 log R_{i,j,k} \tag{1}$$

Table 1. Channel bandwidth and allocated RB per bandwidth.

Channel bandwidth ($BW_{channel}$)	Number of Resource Blocks (N_{RB})
1.4 MHz	6
3 MHz	15
5 MHz	25
10 MHz	50
15 MHz	75
20 MHz	100

Channel Bandwidth Specified in LTE

where λ is the path loss exponent, $d_{i,j}$ denotes distance in km between nodes *i* and *j*, κ is propagation loss, and $\beta_{i,j,k}$ represents log-normal shadowing with a standard deviation of 8 dB and zero mean. The Rayleigh fading power is denoted by $R_{i,j,k}$, using the Rayleigh parameter as *a* with an expected value denoted by *E*, $E[\alpha^2] = 1$.

Data rates

When *N* subcarriers are allocated for transmitting to the j^{th} node. The transmit power and total noise power of a transmitting node *i* is denoted by $P_{i,j,k}$ and $N_{i,j,k}$. The signal-to-noise ratio (SNR) is given by

$$SNR_{i,j,k} = \sum_{i=1}^{I}\sum_{k=1}^{N} \frac{P_{i,j,k} \times G_{i,j,k}}{N_{i,j,k}} \tag{2}$$

where $i = 1, \ldots, I$; $k = 1, \ldots, N$.

The transmitting nodes have a peak-power limitation that power used on all the subcarriers should not exceed $\sum_{k=1}^{N} P_{i,j,k} \le P_{i,max}, i = 1 \ldots I$. Also, let the achievable discrete rate between nodes *i* and *j* while transmitting over subcarrier *k* be denoted by $r_{i,j,k}$. The total rate of any node using *N* subcarriers will be

$$R_{i,j} = \sum_{k=1}^{N} r_{i,j,k} \times SNR_{i,j,k} \tag{3}$$

For continuous rates, the formula for Shannon capacity can be used, i.e. $log_2(1 + SNR_{i,j,k})$. The discrete rate and MCS associated with it are given in the studies of Kumar et al. (2019), E. Universal and T. Radio (2017), and 3GPP TS 36.213 (2016). Therefore, the rate $R_{i,j}$ of transmission between nodes *i* and *j* using a MCS of rate r_l bits/symbol adopted by all allocated subcarriers assigned is

$$R_{i,j} = \frac{r_l N_{RB}^{(i,j)} N_{SC}^{RB} N_{Symbol}^{SC} N_{Slot}^{TTI}}{T_{TTI}} \tag{4}$$

where $N_{RB}^{(i,j)}$ the number of RBs allocated from node *i* to *j* N_{SC}^{RB} the number of subcarriers/RB N_{Symbol}^{SC} the number of symbols/subcarriers in a one-time slot N_{Slot}^{TTI} the number of time slots/TTI *TTI* the duration of a time slot

Resource-allocation algorithm

The work in this paper is incorporating an M2M device's communication with cell-to-cell (C2C) communication. The M2M devices are smart meters and sensors that periodically transfer the information. The work in the literature reserves a fraction of resources for them, which might result in wastage of resources. The time (t) for which the M2M devices access the network resources is less than their period (T) after which they access the network, i.e. for which reserving resources for it is not a practical solution. The paper divides the incoming M2M requests into two types: delay-tolerant and delay-sensitive denoted by n_{dt}^{M2M} and n_{ds}^{M2M}. The delay-sensitive is given priority over delay-tolerant in CA. The M2M requests considered in this paper are both the stationary and moving M2M devices (connected to a moving vehicle or object). The use of RS reduces the duration of these requests. The delay-sensitive requests are from RS to BS communication. The CA is mostly used for handling RS-to-BS requests and delay-sensitive M2M to RS requests. The proposed resource-allocation scheme uses channel-state information (CSI) for an efficient allocation of RBs in the time frequency domain. The eNB/BS is assigned a set of carrier components (CC) to serve the devices. The M2M devices are mostly not mobile in nature, while C2C devices are mostly mobile. This leads to the heterogeneous nature of devices in terms of their CA capability, carrier qualities, and QoS required by them. Let the available *RBs* with the BS are N_{RB}. The assigned *RBs* to a node is $n_{i,j,c}^{RB}$, i for communication with node j, where $\subseteq N_{RB,j,c}$, c denotes the CC of the *RB* and the total M2M requests at node i are $n_{total} = n_{dt}^{M2M} + n_{ds}^{M2M} + n_{c2c}$. The number of CCs used here is (c_c). The performance of the system can be further improved by changing the MCS used by the device on an *RB.* Let the MCS available be l, where $1 \le l \le L$, 1 provides the lowest transmission and L provides the highest transmission rate achieved by a device on an *RB*.

Phase 1: Depending upon the respective priorities and connectivity to nearby RS, all the M2M requests are assigned one RB and suitable MCS to meet the QoS requirements.

Phase 2: All the M2M and mobile devices with multiple antennas are assigned *RBs* of the same or different *CC*s with the same MCS adopted on all the *CC*s.

The M2M delay-sensitive devices must achieve a rate r while they transmit data D_{max}. The rate using *RB* ($n_{i,c}^{RB}$) on *CC* (c) and MCS (l) is denoted by $r_{i,c}^{l}$. At TTI, the eNB scheduler receives the QoS- and channel-quality requirements of devices; this information is used to generate a matrix A of size $n_{total}(t) \times N_{RB}(t)$, where $n_{total}(t)$ and $N_{RB}(t)$ are many devices sending a connection request and several resource blocks available at a time t. The $(a,b)^{th}$ element of this matrix is $A(a,b)$. The device requests are arranged on priority, i.e. delay-sensitive requests are given preference. The elements of the matrix are delay-sensitive M2M devices (n_{ds}^{M2M}), $1 \le a \le n_{ds}^{M2M}$, followed by delay-tolerant and C2C devices, $(n_{ds}^{M2M} + 1) \le a \le n_{dt}^{M2M} + n_{c2c}$.

The algorithm starts working on the network that has been used for some time. The algorithm named as a priority in relays for M2M devices (PR-M2M) works as follows.

First, the eNB requests devices to provide details of their QoS and carrier-quality requirements for the current slot. The eNB then assigns a CC and the corresponding *RB* to a device depending upon the received information. The primary carrier is assigned first to a device; then CA is used for delay-sensitive devices.

Algorithm

Step 1

If $\left(N_{RB} \ne 0\right)$

Select devices in the order of their descending priority and assign *RBs* of a *CC* as a primary carrier and then assign secondary carriers. Assign $n_{j,c}^{RB}$ i.e. j^{th} *RB* of c^{th} *CC* to the device $n_a, 1 \le a \le n_{ds}^{M2M}$. The CA capability of the devices is denoted by $c_a, 1 \le c_a \le 5$. Let z be the set of available *RBs* that will be assigned to the device n_a, then $z \le c_a$

If (all the *RBs* $\in$ the same CC)

Assign the maximum value of MCS in TTI as all *RBs* can use the same MCS.

Else

Find ($\max_{c \in c_c} l_c$) *i.e* maximum value of MCS possible for all CCs and use this MCS on all CCs.

End

Step 2

Update $N_{RB} = N_{RB} - z$

Else if ($N_{RB} = 0$ and $n_{ds}^{M2M} \ne 0$)

Find C2C devices that are not on a two-year contract, *i.e* using prepaid services. Reassign *RBs* to them, assign only one primary carrier to them, and release the remaining *RB* for utilization by priority M2M devices. Go to step 1.

The *RBs* assigned to the delay-sensitive M2M devices are assigned to other devices when they become free.

LTE resource allocation

In this section, a channel model and data-rate calculation explained is followed by an assignment scheme. The assignment scheme applies to the existence or absence of RSs.

Scheduling algorithms

Proportional fair (PF)

The proportional fair schedule is used to maximize the system throughput while maintaining fairness among users. The average throughput or user rate is expressed in the following formula:

$$p = \frac{argmax}{s} \sum_{k \in U} \log R_k^S(t) \tag{5}$$

Exponential proportional fair (EXPF)

The EXPF algorithm is a channel-aware scheme that considers QoS constraints when delivering resources to users within a certain period. This takes into account the characteristics of the PF algorithm and the exponential function. The real-time flow-metric calculation is as follows:

$$m_{i,k}^{EXP/PF} = \exp\left(\frac{\alpha_i D_{HOL,i} - X}{1 + \sqrt{X}}\right) . \frac{d_k^i(t)}{\bar{R}^i(t-1)} \tag{6}$$

where

$$X = \frac{1}{N_{rt}} \sum_{i=1}^{N_{rt}} \alpha_i D_{HOL,i}$$

HOL is the head-of-the-line packet.

Adaptive proportional fair (APF)

The adaptive proportional fair scheduler operates in two modes as a PF scheduler for best-effort services and as an Exponential proportional fair scheduler for delay-sensitive requests.

Results

The information for network parameters is in Table 2; the channel bandwidth of the total system is 40 MHz, for CA, mode 2 CC is at 2.0-GHz frequency, and per-CC bandwidth is 20 MHz. The total number of *RB*s in one CC is 100 with subcarrier spacing 15 kHz and subcarriers in one *RB* are 12. The subframe period is 1ms. The transmission mode of MIMO used is 8 × 8 and simulation time 5,000 TTI. The work is evaluated using variation in two hops and one-hop relay stations. The HOL packet-delay threshold is taken as 20ms, the buffer of each device is infinite, and a lost packet is retransmitted when lost. There are around 90 to 110 devices with a cell radius of 0.3 Km; the devices are distributed uniformly. The work is compared with Proportional Fair (PF) (Liao et al., 2014; Ramli et al., 2009; Jonh-Hun et al., 2004), Exponential Proportional Fair (EXPF) (Ramli et al., 2009), and Adaptive Proportional Fair (APF) (Jonh-Hun et al., 2004). The metrics of evaluation are average packet-dropping probability and average user throughput. The delay-sensitive communication algorithm considers the availability of resources before their allocation to minimize packet-dropping probability that is caused by packet-exceeding time delay (Xu et al., 2019). The evaluations are done using Vienna LTE-A Simulator (Vienna University of Technology (Institute of Telecommunications, 2016) for link-level simulation. In Figure 3, the packet-dropping probabilities of all schemes are compared with the proposed PR-M2M-relay method; the dropping probability increases with increased arrival rates due to the congested network. The packet-dropping probability is calculated as

Table 2. Network parameters.

Parameter	Value
Total channel bandwidth	40 MHz
Frequency	2. 0 GHz
LTE bandwidth	20 MHz per CC
Resource blocks	100
Subcarrier spacing	15 kHz
Subframe period	1 ms
MIMO	8 × 8
Scheduler	Proportional fair
Simulation time	5000 TTI
Slot duration	0.5 ms
Subcarriers	12 per resource block

$$\textit{Packet Dropping Probability} = \frac{\textit{Discarded Packet}}{\textit{Total Packet}} \tag{7}$$

The two-hop method of PR-M2M provides the least dropping probability as before the selection of a relay device; the relay link between relay and eNB

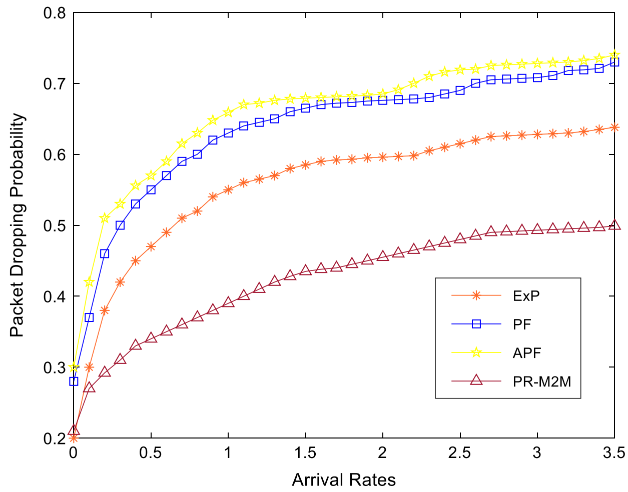

Figure 3: ExP, PF, APF and PR-M2M – Packet Dropping Probability comparison.

is checked for SNR, together with the access link between relay and device. The ones with optimum SNR are selected. In the one-hop method, the access link with optimum SNR is selected. In Figure 4, the throughput of the devices is demonstrated with and without relays with varying distances. The throughput is calculated as

$$\textit{System Throughput} = \frac{\textit{Total Transmitted Packet}}{\textit{Total Simulation Time}} \tag{8}$$

The use of higher adaptive modulation and coding (AMC) decreases the sensitivity level. Therefore, at cell edges where the signal level is low, the higher AMCs are used to maintain the connectivity with eNB, and thus lower AMCs are used at the cell edges. This leads to a decrease in the throughput of the device. The two-hop relay is used when the SNR of the device in a particular AMC is below its threshold even after increasing the code rate. In our case, relay devices are mostly fixed, so connectivity with eNB is always with better SNR. The results clearly show that using a relay station for M2M devices with C2C devices increases throughput.

Conclusions

Future networks are designed with consumers in mind and the service to be the differential that dictates how the different virtual users are best served. The consumer interface is rapidly changing from C2C to include D2D, and hence the packet-loss ratio, fairness enhancement are parameters that must meet the highest acceptable standard. Therefore, the work in this paper maximizes the throughput and reduces the packet-blocking probability. Previously, the PR-M2M Algorithm scheme is designed to meet the demand for M2M and C2C communication that are more prone to higher packet dropping and lesser throughput. The work is better than novel schemes available in the literature. The results obtained indicate that the scheme is superior to two industry-

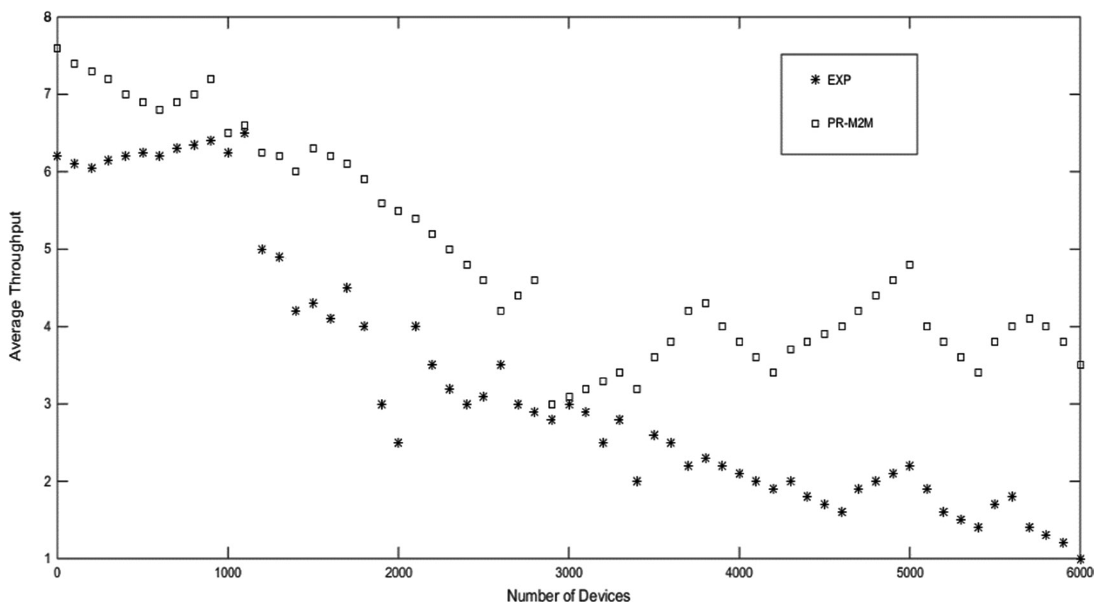

Figure 4: EXP and PR-M2M average throughput.

approved resource-allocation schemes herein. The findings of the study indicate that with HetNets, the PR-M2M scheme is crucial in handling the influx of machine-to-machine (M2M) communication because it gives higher throughput and better packet-dropping probability.

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