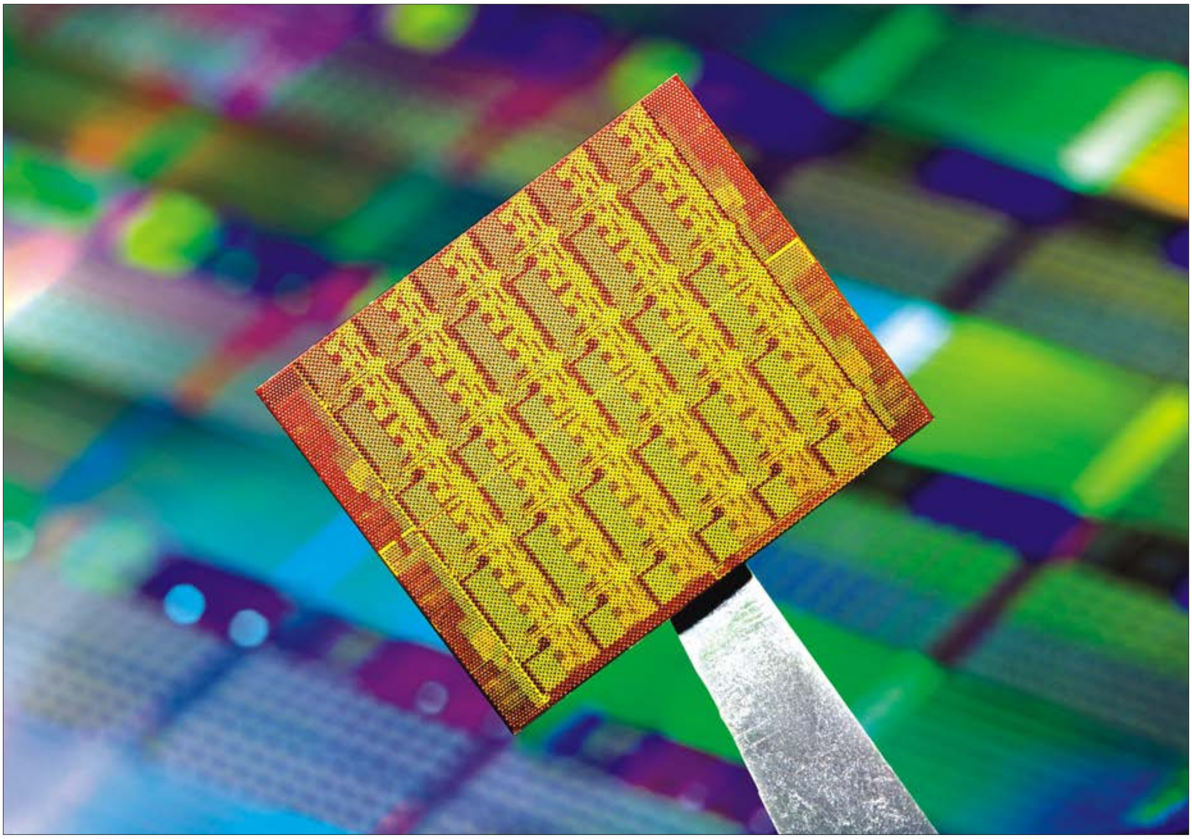

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Research Article
Modeling Efficient Radio Resource Allocation Scheme for MTC and HTC over Mobile Wireless Networks

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Abstract

Background and Objective: MTC traffic cannot access radio channels reserved for HTC traffic even if the channels are idle and vice versa which leads to the underutilization of the radio channels. Therefore, the objective of this study was to model an improved channel allocation scheme, where portions of the radio channels are reserved for each of MTC and HTC traffic but each traffic can access channels reserved for the other traffic when not in use. **Methodology:** To overcome the above challenge, this study proposed a channel allocation scheme to increase the channel utilization. The proposed channel allocation scheme was then analyzed basing on the blocking probability. Queuing theory was employed to derive expressions for blocking probability of MTC and HTC traffic. The performance of the improved radio channel allocation scheme was compared to the channel allocation scheme where MTC traffic cannot access channels reserved for HTC traffic when not in use and vice versa using MATLAB. **Results:** Numerical results showed that the improved radio channel allocation scheme reduces the blocking probability of packets which in turn improves the system performance. It was further noted that the threshold values of channels set for HTC and MTC traffic have an effect on the blocking probability. In addition, channel utilization and blocking probability are observed to increase with increase in arrival rate and packet sizes. **Conclusion:** The improved channel allocation scheme reduces the blocking probability of traffic which in turn improves system performance.

Key words: Channel allocation, blocking probability, MTC traffic, HTC traffic, radio resource,

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INTRODUCTION

The Internet of Things (IoT) will most likely be considered the major technological breakthroughs of the years to come. The term Internet of Things (IoT) describes the increasing cross-linking of smart devices like sensors and actuators referred to as things[1]. Wireless networks have begun to replace the greatest parts of wired networks and are expected to cover most parts of the world. Wireless cellular networks bring with it benefits that include availability in diverse geographical areas and cost effectiveness, which may increase their deployment in a number of applications. Wireless infrastructure used in cellular communication was initially meant to meet the human type communication (HTC) or voice data mostly referred to as Human-to-Human (H2H) communication[2]. Devices in H2H communication are too equipped with more and more computational capacity[3].

The remarkable growth in capabilities of computing machines has enabled gadgets to interact with each other directly or with minimal or no human intervention, leading to MTC or Machine to Machine (M2M) communications which allows devices to exchange data and services for some applications through the communication networks[1]. MTC traffic reduces the dependency of devices over human actions, making them self-sufficient to initiate the actions based on the available network information. In 2012, the number of interconnected devices was estimated to be 9 billion and this is expected to reach 24 billion by 2020[4].

Compared to H2H communication, M2M communication has a much wider range of characteristics[5,6]. For example, these devices can have limited access or none to a power source, thus they must be designed to reduce as much as possible the energy consumption, these devices are operating in the unlicensed bands and considering the widespread deployment, a coexistence issue needs a careful design to reduce the impact on existing traditional networks operating in the same bands (e.g., WiFi and bluetooth).

In most applications, an M2M device needs to report sensed data to the M2M server at regular time periods, the M2M server then processes the collected sensed data after receiving them from M2M devices[7]. M2M communication procedure is preset and therefore, the traffic model is more stable than human-based applications[8,9].

Radio resource management schemes are needed in wireless networks to ensure that the incoming traffic from the accepted MTC-based devices can be served using the available limited resources while ensuring that these devices will not experience a resource starvation[7]. Resource issues include determining with which users to establish connections and assigning transmit power levels to connected users subject to acceptable signal quality.

Queue management, admission control, power and traffic scheduling are the most important components involved in the design of an efficient radio resource management framework[10]. Admission control can be used to balance the goals of maximizing bandwidth utilization and ensuring sufficient resources for high priority service classes. Admission control schemes not only have to ensure that the network meets the service levels of newly arriving requests if accepted but should also guarantee that the service levels of existing requests does not deteriorate. Some admission control schemes are known to prioritize the users into different service classes to maintain their QoS requirements[3].

The complexity of using the existing wireless infrastructures for MTC traffic in an environment that was optimized for HTC traffic presents a number of challenges on top of ensuring maximum utilization of the channel.

Lee *et al.*[11] investigated the random access overload problem due to large number of MTC devices in LTE-A networks. The authors analyzed the throughput performance of two methods for random access preamble allocation and management, proposed for possible adoption in LTE-A networks. In the first method, the available set of random access preamble is split into a subset for human-to-human (H2H) customers and another subset for M2M customers/devices. In the second method, the available set of random access preamble is split into a subset for H2H customers only and a subset for both H2H and M2M customers. Their study showed that there is a boundary of random access load below which the second method outperforms the first method slightly but above which the second method degrades the throughput significantly.

Pang *et al.*[12] proposed a mechanism to guarantee the performance of H2H and M2M in the random access procedure of LTE-A (RACH procedure). In this study a game-theoretic framework which divides the random access to resources into three groups is considered: For H2H, for M2M and for the hybrid usage. However, the challenge with this technique is that traffic for H2H cannot access resources strictly reserved for M2M and vice versa. This study proposed an analytical methodology based on the Continuous Time Markov Chain to analyse the radio resource allocation with the objective of decreasing blocking probability and increasing utilization.

MATERIALS AND METHODS

Sidhu *et al.*[3] proposed a Continuous Time Markov Chain model-based Radio Resource Management scheme which allocates the radio channels to HTC traffic and MTC traffic by introducing a dedicated shared area that provides QoS isolation between HTC traffic and MTC traffic.

The probability that the HTC traffic comes and finds that all shared radio channels are busy is derived as[3]:

$$P_{HTC} = \frac{1}{Kh!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{Kh} \cdot \frac{1}{Ns!}\left(\frac{\lambda_{HTC}+\lambda_{MTC}}{\mu_{HTC}+\mu_{MTC}}\right)^{Ns} . P_o \quad (1)$$

Where:

$$P_o = \left[1 + \sum_{j=1}^{Kh} \frac{1}{j!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{j} + \sum_{k=1}^{Ns} \frac{1}{Kh!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{Kh} \cdot \frac{1}{k!}\left(\frac{\lambda_{HTC}+\lambda_{MTC}}{\mu_{HTC}+\mu_{MTC}}\right)^{k}\right]^{-1} \quad (2)$$

In the same vein, the probability that the MTC traffic comes and finds that all shared radio channels are busy is derived as[3]:

$$P_{MTC} = \frac{1}{Km!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{Km} \cdot \frac{1}{Ns!}\left(\frac{\lambda_{HTC}+\lambda_{MTC}}{\mu_{HTC}+\mu_{MTC}}\right)^{Ns} . P_o \quad (3)$$

Where:

$$P_o = \left[1 + \sum_{j=1}^{Km} \frac{1}{j!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{j} + \sum_{k=1}^{Ns} \frac{1}{Km!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{Km} \cdot \frac{1}{k!}\left(\frac{\lambda_{HTC}+\lambda_{MTC}}{\mu_{HTC}+\mu_{MTC}}\right)^{k}\right]^{-1} \quad (4)$$

The channel utilization is also further given[3]. Although this scheme provides QoS to HTC and MTC traffic, MTC traffic cannot access radio channels reserved for HTC traffic and HTC traffic cannot access radio channels reserved for MTC traffic which leads to the underutilization of the radio channels.

This study used analytical methodology to evaluate the performance of the proposed models. Analytical methodology is a generic process combining the power of the scientific method with the use of formal process to solve any type of problem. An analytical model therefore is a set of computational algorithms or formulae used to analyze systems. Analytical models provided faster and more computationally efficient methods of obtaining performance measures.

In particular, the blocking probability was modeled using Continuous Time Markov Chain (CTMC). A CTMC can be described by its state transition characteristics. Basically a Continuous-Time Markov Chain is one in which changes to the system can happen at any time along a continuous interval. Unlike Discrete-Time Markov Chain where changes to the system can only happen at one of the discrete time values. The Markov Chain may be represented as a two dimensional extension of the M/M/m/m queue or as two separate single dimensional M/M/m/m queues, where the first M represented Markovian arrival process, the second M represented exponential service time, the third m represented the number of servers and the last m represented the service capacity of the queues.

System model: The study considered a system model consisting of a base station (BS) that supports HTC and MTC traffic using a wireless technology. The BS was assumed to contain N radio channels. The admission control residing in the BS manages the N radio channels between the MTC and HTC traffic. The arrival process of HTC and MTC traffic are assumed to follow two independently Poisson Processes with parameters λ_{HTC} and λ_{MTC}, respectively. The service time of the HTC and MTC traffic are assumed to follow the exponential distribution with rates μ_{HTC} and μ_{MTC}, respectively. To provide a QoS isolation between MTC and HTC traffic, the proposed radio resource management scheme reserves K_h channels for HTC traffic and Km channels for MTC traffic, distributed over the N radio channels. Each of the reserved channels is intended to ensure that a portion of the radio resources is dedicated to each service class as shown in Fig. 1.

To increase the resource allocation flexibility, traffic from HTC is allowed to access channels reserved for MTC traffic when not in use and traffic from MTC is allowed to access channels reserved for HTC traffic when not in use. Queues are introduced for traffic of each class waiting for service.

The working of the flowchart is such that whenever a service request arrives in the system, it is checked against the number of channels reserved for that class, if the channels are available the request is accepted in the reserved channel for processing, if the reserved channels for that class are occupied and the channels reserved for the other class of traffic is available, it is accepted for processing in the reserved channels for the other class of traffic. If all the channels are occupied, the incoming request is placed in the queue of its class and if the queue is full the request is dropped. If the incoming HTC requests arrive in the system, the number of channels reserved for HTC requests are compared against the requirement for the HTC incoming requests. If the channels are available, the

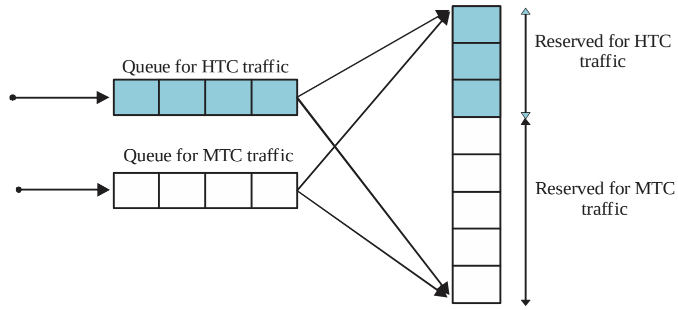

Fig. 1: Proposed radio resource management scheme

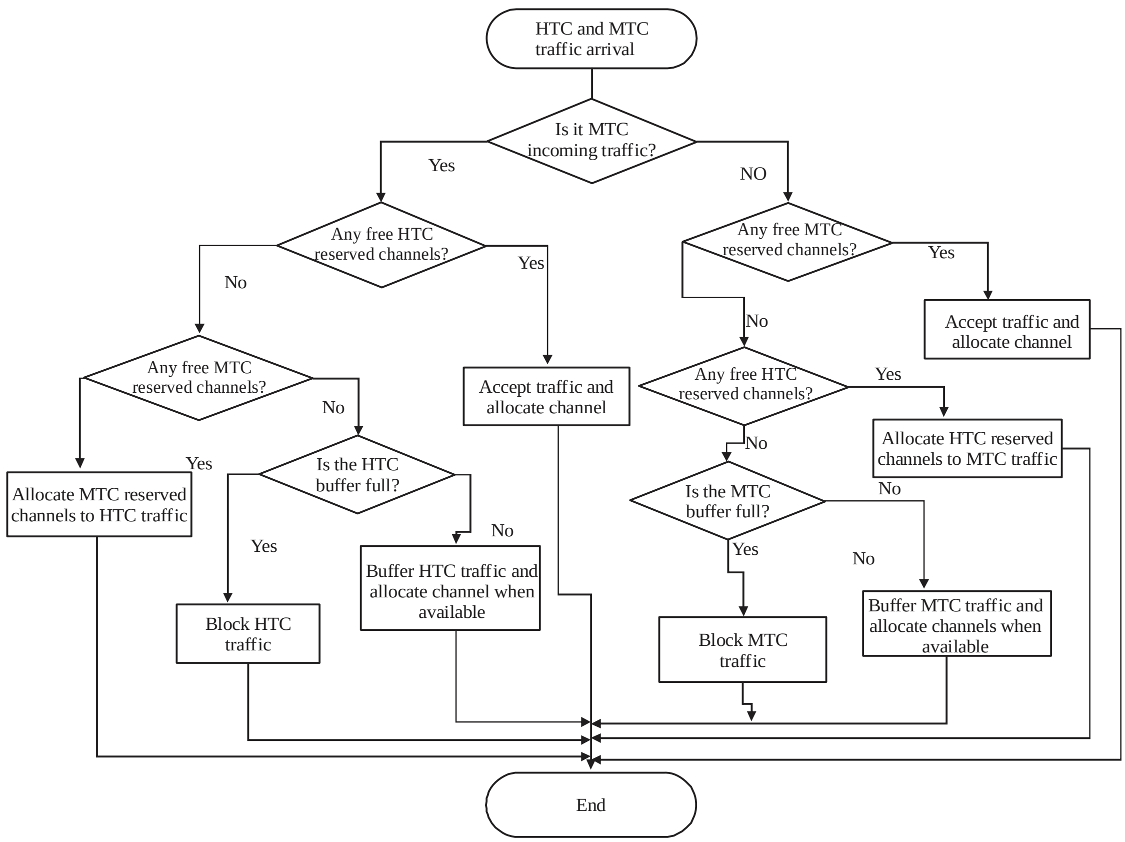

Fig. 2: Flowchart for the proposed radio resource management scheme

requests are accepted for processing and if the reserved channels are occupied, the channels reserved for MTC traffic are checked for availability and the requests are Km accepted for processing. On the other hand, if all the channels are occupied, the incoming HTC requests are placed in the queue for H2H traffic and if the queue is full the request is dropped. Similarly, if the incoming MTC requests arrive in the system, the number of channels reserved for MTC requests are Km compared against the requirement for the MTC incoming requests. If the channels are available, the requests are accepted for processing, if the reserved channels are occupied, the channels reserved for H2H traffic are checked for availability and the K_h requests are accepted for processing. On the other hand if all the channels are occupied, the incoming MTC requests are placed in the queue for MTC traffic and if the queue is full the request is dropped. The flow chart for the working of the system is shown in Fig. 2.

Derivation of blocking probability for the radio resource allocation scheme: The radio resource allocation scheme proposed by Sidhu[3] leads to wastage of bandwidth since HTC traffic cannot access the channels reserved for MTC traffic and vice versa even when the channel is idle. The proposed radio channel allocation scheme takes this problem into account. In this scheme, both the HTC and MTC traffic are allowed to access all the channels if they are free on first come first served basis. This allowed the users to use the full capacity of the system. Two cases are analyzed to determine the blocking probability.

- **Case I:** When the channels reserved for HTC traffic are not fully occupied, i.e., $i \le K_h$, in this case, we analyzed the status of the channels reserved for HTC traffic and the radio channels reserved for MTC traffic, respectively. Let P_i be the probability that there are i calls in the channels reserved for HTC calls:

$$P_i = \frac{1}{i!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^i P_{oHTC} \qquad i \le K_h$$

Where:

$$P_{oHTC} = \left[1 + \sum_{i=1}^{H} \frac{1}{i!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^i\right]^{-1}$$

On the other hand, the stationary distribution of the channel reserved for MTC calls is deduced as follows: Let P_j be the probability that there are j calls in the channels reserved for MTC calls, then:

$$P_j = \frac{1}{j!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^j P_{oMTC} \qquad j \le (K_h + N_s)$$

$$P_{oMTC} = \left[1 + \sum_{j=1}^{(K_h+N_s)} \frac{1}{j!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^j\right]^{-1}$$

The blocking probability of MTC traffic is then given as:

$$P_{MTC} = \frac{1}{K_h!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{K_h} \frac{1}{(K_h + N_s)!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{(K_h+N_s)} .P_{oHTC}.P_{oMTC} \qquad (5)$$

- **Case II:** When the channels reserved for HTC traffic are fully occupied, i.e., $i = K_h$, in this case, the coming MTC calls will share the remaining (Km+Ns) channels. Let P_k be the probability that there are k channels in the channels reserved for MTC calls. According to the state transition diagram:

$$P_k = \frac{1}{K_h!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{K_h} \frac{1}{k!}\left(\frac{\lambda_{HTC} + \lambda_{MTC}}{\mu_{HTC} + \mu_{MTC}}\right)^k .P_o \qquad (6)$$

Where:

$$P_o = \left[1 + \sum_{i=1}^{K_h} \frac{1}{i!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^i + \sum_{k=1}^{(K_m+N_s)} \frac{1}{K_h!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{K_h} \frac{1}{K!}\left(\frac{\lambda_{HTC} + \lambda_{MTC}}{\mu_{HTC} + \mu_{MTC}}\right)^k\right]^{-1}$$

The blocking probability P_{HTC} that the coming HTC call comes and finds that all channels are busy can be derived as follows:

$$P_{HTC} = \frac{1}{K_h!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{K_h} \frac{1}{(K_m + N_s)!}\left(\frac{\lambda_{HTC} + \lambda_{MTC}}{\mu_{HTC} + \mu_{MTC}}\right)^{(K_m+N_s)} .P_o \qquad (7)$$

On the other hand, when the channels reserved for MTC calls are fully occupied, i.e., $j = Km$, in this case, the coming HTC calls will share the remaining Kh+Ns channels with MTC calls. Let P_k be the probability that there are k channels in the channels reserved for HTC call. According to the state transition diagram:

$$P_k = \frac{1}{K_m!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{K_m} \frac{1}{k!}\left(\frac{\lambda_{HTC} + \lambda_{MTC}}{\mu_{HTC} + \mu_{MTC}}\right)^k .P_{oMTC} \qquad (8)$$

Where:

$$P_{oMTC} = \left[1 + \sum_{j=1}^{K_m} \frac{1}{j!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^j + \sum_{k=1}^{(K_h+N_s)} \frac{1}{K_m!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{K_m} \frac{1}{K!}\left(\frac{\lambda_{HTC} + \lambda_{MTC}}{\mu_{HTC} + \mu_{MTC}}\right)^k\right]^{-1} \qquad (9)$$

The blocking probability P_{MTC} that the coming MTC call comes and finds that all channels are busy can be derived as follows:

$$P_{MTC} = \frac{1}{K_m!}\left(\frac{\lambda_2}{\mu_2}\right)^{K_m} \frac{1}{(K_h + N_s)!}\left(\frac{\lambda_1 + \lambda_2}{\mu_1 + \mu_2}\right)^{(K_h+N_s)} .P_{oMTC} \qquad (10)$$

where, Po_{MTC} is as given in equation 8. With the above scheme, when HTC and MTC calls are queued, the blocking probability of HTC calls and the blocking probability of MTC calls can be deduced as follows: Let the queue size of HTC and MTC calls be Q each. A HTC call will be blocked when all the N channels are used up and its queue is full, on the other hand, an MTC call will be blocked if all the channels are busy and its queue is also full. The modified blocking probability of HTC call is then given as below:

$$P_{HTC} = \frac{1}{K_h!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{K_h} \frac{1}{Q!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{Q} \frac{1}{(K_m + N_s)!}\left(\frac{\lambda_{HTC} + \lambda_{MTC}}{\mu_{HTC} + \mu_{MTC}}\right)^{(K_m+N_s)} .P_{oHTC} \quad (11)$$

Where:

$$P_{oHTC} = \left[1 + \sum_{i=1}^{K_h} \frac{1}{i!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{i} + \sum_{j=1}^{Q} \frac{1}{j!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{j} + \sum_{k=1}^{(K_m+N_s)} \frac{1}{K_h!}\left(\frac{\lambda_{HTC}}{\mu_{HTC}}\right)^{K_h} \frac{1}{Q!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{Q} \frac{1}{k!}\left(\frac{\lambda_{MTC} + \lambda_{HTC}}{\mu_{MTC} + \mu_{HTC}}\right)^{k} \right]^{-1} \quad (12)$$

The corresponding modified blocking probability of MTC call is given below:

$$P_{MTC} = \frac{1}{K_m!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{K_m} \frac{1}{Q!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{Q} \frac{1}{(K_h + N_s)!}\left(\frac{\lambda_{HTC} + \lambda_{MTC}}{\mu_{HTC} + \mu_{MTC}}\right)^{(K_h+N_s)} .P_{oMTC} \quad (13)$$

Where:

$$P_{oMTC} = \left[1 + \sum_{j=1}^{K_m} \frac{1}{j!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{j} + \sum_{i=1}^{Q} \frac{1}{i!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{i} + \sum_{k=1}^{(K_h+N_s)} \frac{1}{K_m!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{K_m} \frac{1}{Q!}\left(\frac{\lambda_{MTC}}{\mu_{MTC}}\right)^{Q} \frac{1}{k!}\left(\frac{\lambda_{HTC} + \lambda_{HTC}}{\mu_{HTC} + \mu_{HTC}}\right)^{k} \right]^{-1} \quad (14)$$

- **Derivation of the channel utilization:** Since the HTC traffic are allowed access to radio channels reserved for MTC traffic and MTC traffic are allowed access to the radio channels reserved for HTC traffic, the channel utilization is the same as for complete sharing scheme

According to the stationary distribution of complete sharing scheme, we can derive the expected number of busy channels in the cell, L. Hence, the channel utilization percentage α of the improved radio resource scheme is described as follows:

$$\alpha = \frac{L}{Nch} = \frac{\sum_{k=1}^{Nch} k.P_k}{Nch} \quad (15)$$

Where:

$$P_k = \frac{\left(\frac{\lambda_{HTC} + \lambda_{HTC}}{\mu_{HTC} + \mu_{MTC}}\right)^{k}}{k!}.P_o \quad (16)$$

where, P_o is as given in Eq. 17:

$$P_o = \left[\sum_{k=o}^{Nch} \frac{\left(\frac{\lambda_{HTC} + \lambda_{MTC}}{\mu_{HTC} + \mu_{MTC}}\right)^{k}}{k!} \right]^{-1} \quad (17)$$

Next, the performance of the derived models was evaluated.

RESULTS

For numerical evaluation the following hypothetical data was considered, is the same as the configurations used in Sidhu *et al.*[3].

The threshold values for the number of channels reserved for MTC and HTC are given in Table 1.

Impact of the variation of the arrival rate of HTC and MTC traffic on the blocking probability of HTC traffic: The arrival rate of the HTC and MTC traffic is varied and the impact of this variation on the blocking probability of HTC data packets is investigated. The results are illustrated in Fig. 3, 4 and 5.

In Fig. 3, it can be observed that the improved radio resource management scheme reduces the blocking probability of HTC traffic as compared to the original radio management scheme. The reduction in blocking probability is as a result of allowing HTC traffic access to the radio channels reserved for MTC traffic in addition to the radio channels reserved for HTC traffic. Thus, when HTC traffic are allowed access to the radio channels reserved for MTC traffic, there are lower chances of having the HTC packets dropped and hence reduction in blocking probability. It can be further observed that when the arrival rate of the MTC traffic increases, the blocking probability of the HTC traffic also

Table 1: Threshold values of MTC and HTC varied at different values

Thresholds set I		Thresholds set II		Thresholds set III	
K_h	K_m	K_h	K_m	K_h	K_m
10	6	6	9	8	9
12	9	10	9	8	12
14	12	14	9	8	15

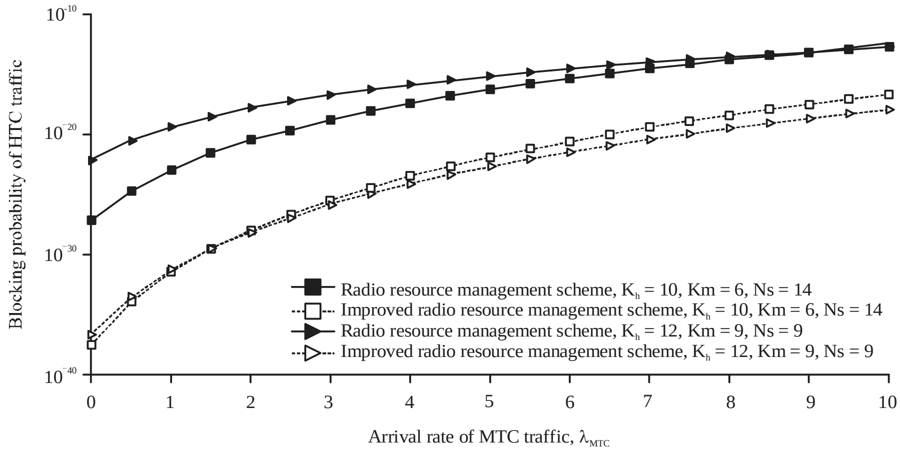

Fig. 3: Blocking probability of HTC versus arrival rate of MTC traffic with varied thresholds

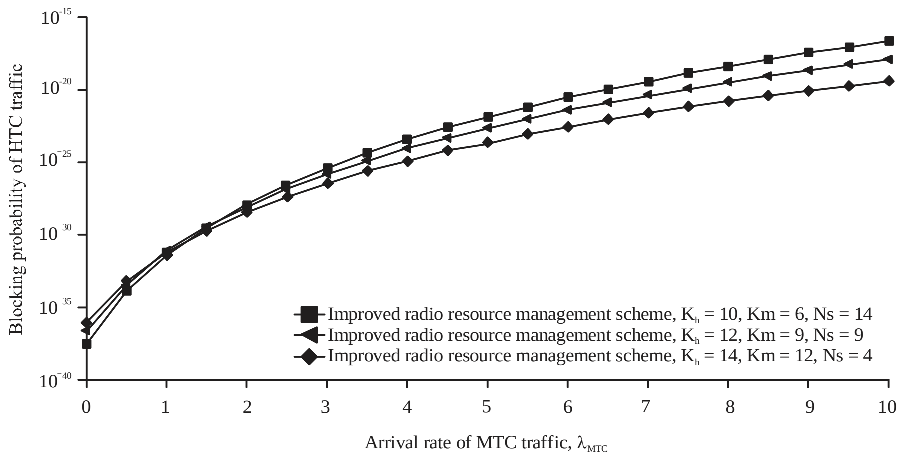

Fig. 4: Blocking probability of HTC versus arrival rate of MTC traffic with varied thresholds

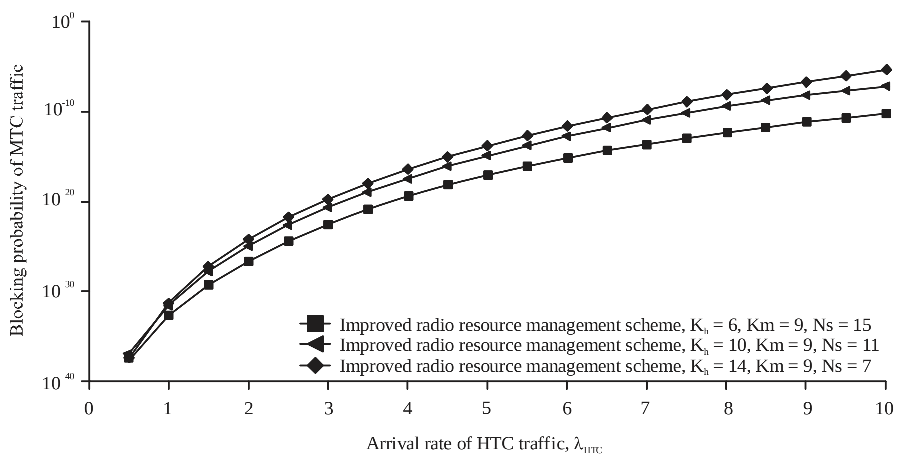

Fig. 5: Blocking probability of HTC versus arrival rate of HTC traffic with constant MTC threshold

increases, therefore there are high chances of having the HTC packets dropped. This relationship between the blocking probability of HTC traffic and the MTC arrival rate is also impacted by the change in the threshold for MTC, HTC and shared areas. Indeed, Fig. 3 shows that if the threshold values for HTC and MTC areas are set to lower values (e.g., K_h =10 and Km = 6) and the threshold of the shared area is set to be greater than K_h and Km, the blocking probability of HTC traffic decreases. Thus, keeping lower threshold values has a greater impact on the arrival of HTC traffic. Lower threshold values ultimately result in bigger shared area, leading to chances of having less HTC data packets dropped.

Figure 4 shows the relationship between the blocking probability of HTC traffic and the arrival rate of MTC traffic with varied thresholds MTC traffic for the improved radio resource management scheme. It can be observed that if the arrival rate of the MTC traffic is low, its impact on the HTC blocking probability is also low. This is due to the fact that all the incoming MTC requests are being served in the MTC reserved area. However as the arrival rate of the MTC traffic increases, the blocking probability of the HTC traffic increases. This observation was caused by the usage of the shared area by the MTC traffic which reduces the number of shared radio channels to be used by HTC traffic. Larger thresholds for HTC traffic mean that there are more dedicated resources for the HTC requests, which in turn imply lower HTC blocking probabilities. This trend was illustrated in Fig. 5 where the blocking probability of HTC traffic for $K_h = 14$ is lower than for $K_h = 10$ which in turn is lower than for $K_h = 6$.

Figure 5 shows the relationship between the blocking probability of HTC traffic and the arrival rate of HTC traffic with constant MTC threshold for the improved radio resource management scheme. It can be observed that if the arrival rate of the HTC traffic is low, its impact on the HTC blocking probability is negligible. This was due to the fact that all the incoming HTC requests are being served in the HTC reserved area. However as the arrival rate of the HTC traffic increases, the blocking probability of the HTC traffic increases. This trend was caused by the competition of the shared area by the HTC and MTC traffic which reduces the number of shared radio channels to be used by HTC traffic and hence leads to increase in blocking probability of HTC traffic. Larger thresholds for the shared area means that there are more radio channels for the HTC requests, which in turn imply lower HTC blocking probabilities. This trend is illustrated in Fig. 7 where the blocking probability of HTC traffic for Ns = 15 is lower than for Ns = 11 which in turn is lower than for Ns = 7.

Impact of the variation of the arrival rate of HTC and MTC traffic on the blocking probability of MTC Traffic: The arrival rate of the HTC and MTC traffic is varied and the impact of this variation on the blocking probability of MTC data packets is investigated. The results are illustrated in Fig. 6 and 7.

Figure 8 shows the variation of blocking probability of MTC versus arrival rate of HTC traffic with varied thresholds. It can be observed that the improved radio resource management scheme reduces the blocking probability of MTC traffic as compared to the original radio management scheme. The reduction in blocking probability was due to the fact that MTC traffic are allowed access to the radio channels reserved for HTC traffic in addition to the shared channels and the radio channels reserved for MTC traffic. When MTC traffic are allowed access to the radio channels reserved for HTC traffic, there are lower chances of having the MTC packets dropped and hence reduction in blocking probability of MTC traffic. It was also observed from the results in Fig. 8 that when the arrival rate of the HTC traffic increases, the blocking probability of the MTC traffic also increases. Increase in HTC traffic implies more competition for the shared areas by HTC and MTC traffic and this increases the chances of MTC traffic being blocked. It is further observed that the blocking probability of MTC traffic is impacted by the change in the number of radio

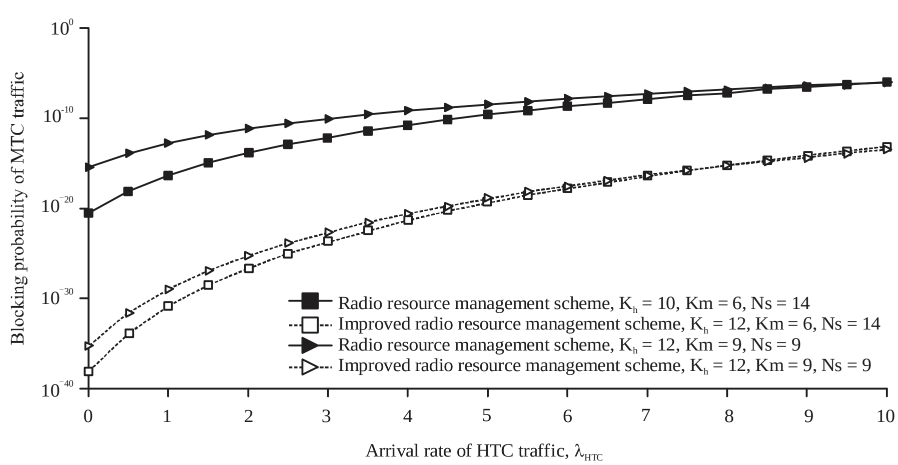

Fig. 6: Blocking probability of MTC versus arrival rate of HTC traffic with varied thresholds

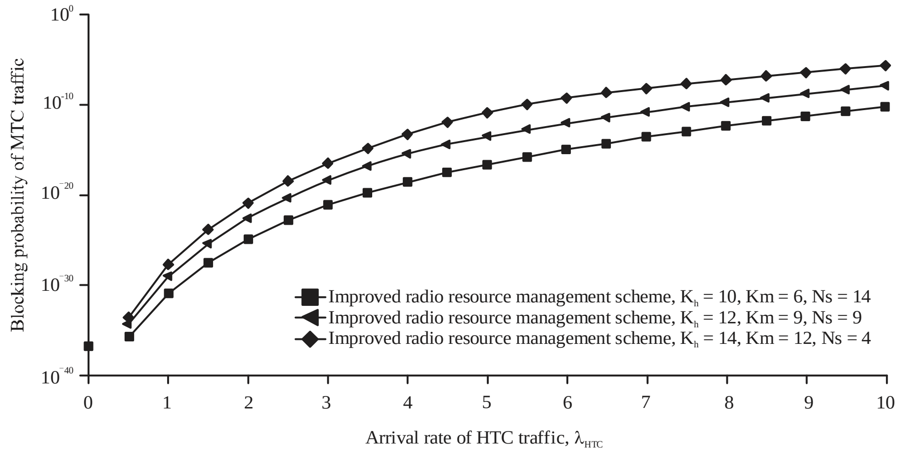

Fig. 7: Blocking probability of MTC versus arrival rate of MTC traffic with varied thresholds for improved Radio Resource Management scheme

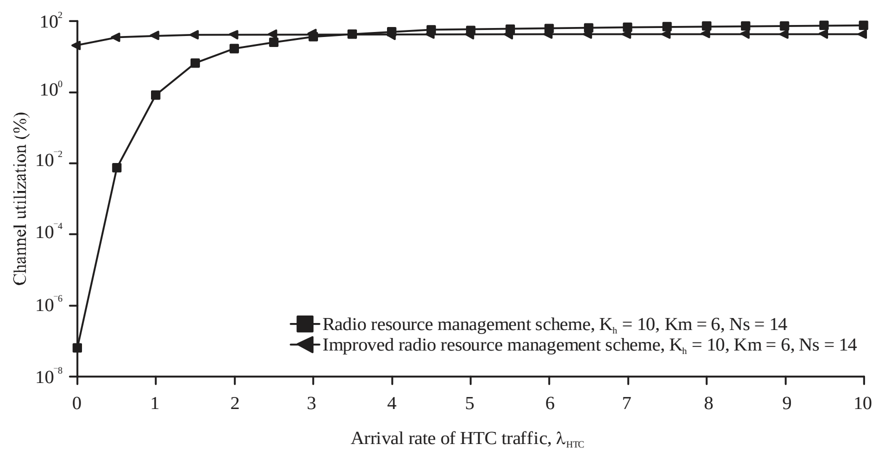

Fig. 8: Blocking probability of HTC traffic versus packet sizes of HTC traffic

channels for the shared areas. For example, if the shared area has Ns = 14 channels, the blocking probability is lower than when the number of channels for the shared area is Ns = 9.

Figure 7 shows the relationship between the blocking probability of MTC traffic and the arrival rate of MTC traffic with varied thresholds for improved radio resource management scheme. It can been noticed that if the arrival rate of the MTC traffic is low, the impact on the HTC blocking probability is also low. This is due to the fact that all the incoming MTC requests are being served in the MTC reserved area. However as the arrival rate of the MTC traffic increases, the blocking probability of the MTC traffic increases. This observation is caused by the usage of the shared area by the HTC traffic which reduces the number of shared radio channels to be used by MTC traffic. It can also be observed that large shared areas reduces the blocking probability of MTC traffic, larger shared areas mean that there are more radio channels for the MTC requests to use, which in turn implies lower MTC blocking probabilities. This trend is illustrated in Fig. 9 where the blocking probability of MTC traffic for Ns = 14 is lower than for Ns = 9 which in turn is lower than for Ns = 4.

Impact of arrival rate of the MTC and HTC traffic on the channel utilization for HTC traffic: In this section, the impact of the arrival rate of the HTC and MTC traffic on the channel utilization for HTC traffic was investigated.

It can be observed from Fig. 10 that the percentage channel utilization generally increases with increase in arrival rate of HTC traffic. It can further be observed that for lower arrival rate of HTC traffic, the channel utilization for the radio resource management scheme is better than the channel

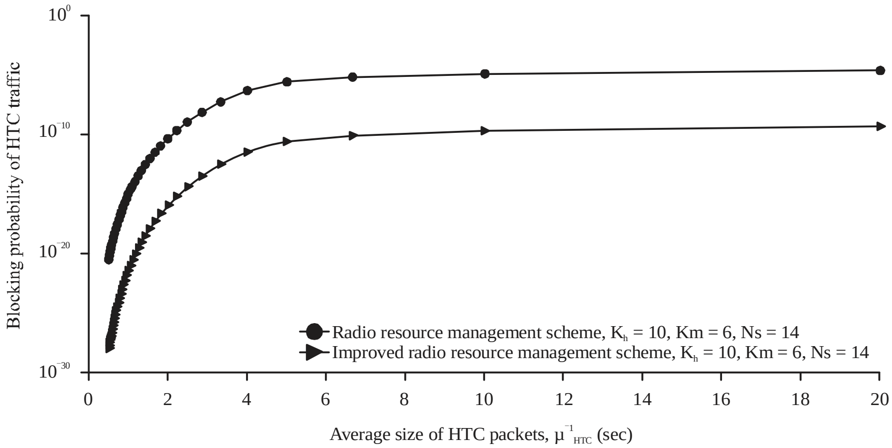

Fig. 9: Blocking probability of MTC traffic versus packet sizes of HTC traffic

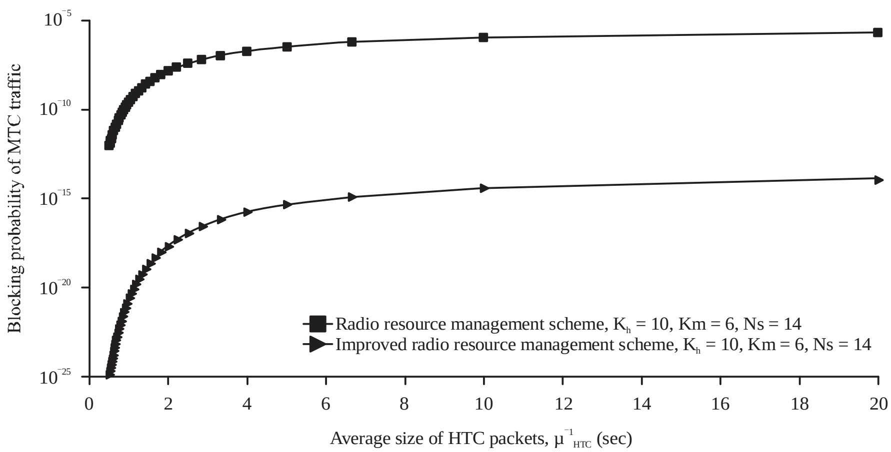

Fig. 10: Percentage channel utilization of the channels for HTC traffic as a function of arrival rate of HTC traffic

utilization for the improved radio resource management scheme. However, for higher values of arrival rate of HTC traffic, the improved radio resource management scheme performs better than the radio resource management scheme. The percentage channel utilization of the improved radio resource management scheme is higher than for the radio resource management scheme because under the improved radio resource management scheme any channel can be accessed by any class of users when they are free, i.e. the HTC traffic can access channels reserved for MTC traffic and MTC traffic can access channels reserved for HTC traffic. The channel utilization for the radio resource management scheme is lower than improved radio resource management scheme at higher arrival rates of HTC traffic because HTC traffic are not allowed access to channels reserved for MTC traffic even when its idle and also MTC traffic are not allowed access to channels reserved for HTC traffic even when its idle.

Impact of packet size of the MTC and HTC traffic on the blocking probability of HTC traffic: In this section, the impact of the packet size of the HTC and MTC traffic on the blocking probability of HTC traffic is studied.

Figure 9 shows the graph of blocking probability of HTC traffic versus packet sizes of HTC traffic. In this case the packet sizes are assumed to be directly proportional to the time required to service the packet. The service time of a HTC packet is given by $\frac{1}{\mu_{HTC}}$ seconds. It can be observed that blocking probability of HTC traffic increases with increase in packet sizes of HTC traffic. This can be explained by the fact that increase in packet sizes implies more time to serve the packet and this reduces the chances of other packets getting served which leads to increase in blocking probability. It is further observed that the improved radio resource management scheme exhibits a lower probability compared to the radio resource management scheme. The improved radio resource management scheme exhibits a better performance because packets are allowed to access channels reserved for other classes. On the other hand, the radio resource management scheme shows a worse performance because packets cannot be allowed access to channels of other classes even when they are idle. It can also be noted that at higher values of packet sizes, the blocking probability remains almost constant.

Impact of packet size of the MTC and HTC traffic on the blocking probability of MTC traffic: In this section, the impact of the packet size of the HTC and MTC traffic on the blocking probability of MTC traffic was studied.

Figure 10 shows the graph of blocking probability of MTC traffic versus packet sizes of HTC traffic. It can be observed that blocking probability of MTC traffic increases with increase in packet sizes of HTC traffic. This can be explained by the fact that when the packet sizes increase the chances of packets getting served is reduced which leads to increase in blocking probability. It can further be observed that the blocking probability of improved radio resource management scheme is lower than the blocking probability of the radio resource management scheme for all values of the packet sizes considered. The blocking probability of improved radio resource management scheme was lower than the blocking probability of the radio resource management scheme due to the fact that improved radio resource management scheme allows traffic from one class to access resources reserved for another class of traffic. Initially the blocking probability of both improved radio resource management scheme and radio resource management scheme increase and then almost remains constant. It can also be noted that increase in packet sizes beyond approximately 5 sec has insignificant effect on the blocking probability.

DISCUSSIONS

Previous studies have focused on efficient radio resource management scheme to accommodate MTC traffic without affecting the regular HTC traffic in the network. In a recent study, Sidhu *et al.*[3] proposed a Continuous-Time Markov Chain (CTMC) model based radio resource scheme where the radio resource is reserved for MTC and HTC traffic and the rest of the resources shared. However, MTC traffic cannot access radio channels reserved for HTC traffic and HTC traffic cannot access radio channels reserved for MTC traffic which leads to the underutilization of the radio channels. This study proposed the improved radio resource management scheme where packets of HTC traffic are allowed to access radio channels reserved for MTC traffic and MTC packets allowed to access radio channels reserved for HTC traffic.

The numerical results obtained from the derived models showed that the improved radio resource management scheme reduces the blocking probability and increases the channel utilization for both MTC and HTC traffic. The reduction in blocking probability and increase in channel utilization is as the result of MTC traffic being allowed to access the channels reserved for HTC traffic when it is not in use and vice versa.

The results further showed that the improved radio resource management scheme provides service guarantee for both MTC and HTC traffic which is better than the radio resource management method proposed by Lien *et al.*[13] which provides QoS guarantees only for MTC traffic, partitioning for H2H and shared for H2H and M2M proposed by Lee *et al.*[11] The improved radio resource management scheme outperforms the complete partitioning for H2H and M2M and hybrid for H2H and M2M proposed by Pang *et al.*[12].

Furthermore, the improved radio resource management scheme outperforms the class-based priority scheduling algorithm proposed by Giluka *et al.*[14] for device to base station communication in LTE networks where a threshold value is set on the MTC traffic to guarantee the QoS of HTC traffic. Setting of the threshold value on the MTC traffic leads to underutilization of the channel.

The improved radio resource management scheme further outperforms the game-theoretic framework proposed by Pang *et al.*[12], which divides the random access resources into three groups: For H2H, M2M and for the hybrid usage. Dividing the resources guarantees QoS for each traffic class but leads to underutilization of the radio resource.

CONCLUSION

This study derived models for the improved radio resource management scheme in terms of blocking probability and channel utilization. The performance of the proposed radio resource management scheme was observed to outperform the performance of radio resource management schemes in terms of blocking probability and channel utilization. Although the mechanism leads to increased channel utilization, the quality of service guarantee for each class of traffic is reduced. In future, the analysis could be extended to other channel allocation scheme like the hybrid channel allocation scheme where the total number of channels available for service is divided into fixed and dynamic sets.

SIGNIFICANCE STATEMENT

This study discovers the possible ways of modeling radio resource management scheme for wireless networks. It is expected that this study will help researchers to uncover possible ways of modeling radio resource management scheme for other radio allocation schemes.

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