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Improved Resource Allocation in 5G MTC Networks

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ABSTRACT Effective resource allocation has always been one of the serious challenges in wireless communication. A considerable number of machine type communication (MTC) devices in 5G with variable quality of service (QoS) aggravates this challenge even further. Existing Resource allocation schemes in MTC are usually considering signal to noise ratio (SNR), which provides preference to MTC devices based on distance rather than their QoS requirements. This paper proposes a resource allocation scheme with dynamic priorities for MTC devices with multiple radio access technologies (RATs). The proposed resource allocation scheme has two main parts namely medium access and resource allocation. The medium access leverages the broadcast nature of wireless signal and MTC devices' wait time to assign priorities using capillary band in a secure and integral way. At resource allocation, SNR, total induced transmission delay, and transmission-awaiting MTC devices are used to assign resources in the cellular band. The rumination of two-staged dynamic priorities in the proposed scheduling scheme brings significant performance improvements in outage and success probabilities. Compared to SNR-based schemes, the proposed mechanism performs well by expressively improving the outage and success probability by 20% and 30%, respectively.

INDEX TERMS Integrity, resource allocation, dynamic priorities, MTC, massive M2M, multi-RATs, security.

I. INTRODUCTION

Machine type communication (MTC) is one of the enabling technologies of fifth generation (5G) networks. The autonomous inter-MTC devices' communication gives rise to unprecedented applications and new business models [1]. However, it also induces many significant challenges as a result of the distinct system requirements [2], [3]. Traditionally, a base station (BS) in a cellular network is responsible to cater all MTC transmissions in its coverage area. The massive number of MTC devices make it impractical for a BS to perform resource scheduling for the human type communication (HTC) devices along with the MTC devices [4]. Therefore, the MTC gateway (MTCG) can be employed to delegate the responsibility of data collection [5]–[9]. In this way, a BS can offload its control and data signaling by mitigating it to the MTCGs in a secure way.

Conventionally, contention-based resource allocation has been used by MTC devices to access an MTCG [10]–[14] along with the compressed sensing [15]. However, the performance of contention-based resource allocation significantly deteriorates with the increasing number of MTC devices, which also brings the issues of privacy. With the assistance of a BS, an aggregator can perform resource scheduling to enable communication among MTCG and MTC devices [16]. The authors in [17] proposed the use of MTCGs by augmenting it with intelligence, such as spectrum sharing and resource scheduling. By doing so, the gateways may control

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communications among MTC devices that show better performance in cellular networks [18].

The existing literature that addresses the above mentioned challenges include [19]–[24], [25]–[29]. Using stochastic geometry, the authors in [20] have investigated the signal to interference ratio (SIR) for relaying and aggregation phases. The authors have proposed a channel-aware resource scheduling scheme as a benchmark. Their proposed scheme preferentially assigned available channel resources to MTC devices with better fading or signal to noise ratio (SNR). The fixed resource consideration has confined its performance only to equal resource-demand scenario. This issue has been resolved by [19] with the provision of dynamic resource allocation scheme. The authors in [19] have derived the expression for outage probability along with analytically calculating the maximum MTC devices' density under the outage constraint. The authors in [21] have extended the work of [20] by proposing a hybrid OMA-NOMA (non orthogonal multiple access)-based data aggregation mechanism. Primarily focusing on the aggregating phase, this work advocates to use NOMA for an MTC device-Aggregator link. Despite being useful, all these proposed scheduling schemes provide preferential treatment to MTC devices with better SNR. In this way, MTC devices that lie close to the MTCG are preferred over distant devices (possibly with comparable SNRs) irrespective of their QoS heterogeneity, security and privacy.

The challenges pertaining to scheduling resources with variable QoS requirements of MTC devices is addressed in our previous work [22]. The proposed scheme considered that all the MTC devices are working in a group and termed it as class. The properties of a class such as those MTC devices, which are waiting for the transmission is also considered as a parameter in addition to queuing delay and QoS requirements. The proposed scheme significantly improved the energy efficiency and system capacity. However, the MTC devices were required to send their transmission requests to an MTCG using random access. It means that MTC devices can get a preferential treatment only if they are "lucky" to successfully pass through the contention phase, which is a major performance impediment.

The motivation behind the proposed scheduling scheme in this article is multi-fold. Firstly, it is believed that a mere consideration of SNR is not enough to fulfill the variable QoS requirements of MTC devices. In this way, MTC devices that lie close to an MTCG are usually preferred, depriving the distant devices with comparable SNR levels. Secondly, the authors in [19] and [20] considered that an MTCGs invariable get resources from the BS, which is not practical. Lastly, the proposed schemes in [19], [20], [22] used conventional random access mechanism for the contention phase to access an MTCG to send their transmission requests, which treats all transmission requests with the same probability. The problem with this approach is that even though higher priority MTC devices can be granted resources on preferential basis, it is only possible if they are successful at the contention phase where all devices are treated equally.

According to [3], [30], [31], a multi-RAT MTC device is capable of communicating in capillary and cellular bands. This motivated us to propose a scheduling scheme that leverages multiple RATs to jointly consider MTC devices in MTC cellular and capillary networks, under diverse QoS requirements in addition to privacy and security. The proposed scheduling algorithm has two main phases, medium access and allocation. In medium access phase, the capillary interface is used to allow an MTC device to preferentially access an MTCG. Whereas, in the allocation phase, the available cellular channel resources are allocated to perform data transmission. In this way, the snag of using random access at the contention phase in the existing resource allocation schemes can be mitigated by allowing preferential access.

The prioritized access in the proposed algorithm renders opportunity to groups of MTC devices to complete their transmissions on preferential basis, which improves the overall success probability of the MTC network.

Our scheme is designed and developed with security in mind, taking into consideration common security aspects: access control, authentication, nonrepudiation, data confidentiality, communication security, data integrity, availability, and privacy.

At medium access phase, the proposed scheme leverages devices' priorities to increase the chances of successful transmissions. The devices' priority is calculated using inter-frame and intra-frame wait times in addition to transmission-awaiting MTC devices in a class. At the allocation phase, the proposed scheme preferentially allocates scarce channel resources to meet the maximum delay tolerance of MTC devices by additionally considering their total induced wait time and received SNR. The performance analysis reveals that the proposed scheduling scheme outperforms existing schemes by significantly improving system capacity in addition to success and outage probabilities.

The remaining sections of this paper are structured as follows: Section II describes the system model followed by the proposed resource allocation scheme in Section III. Performance analysis is elucidated in Section IV, while Section V ends up the article.

II. SYSTEM MODEL

The uplink transmission model with the staunch presence of MTCGs is considered in the proposed study. An MTCG can be a stationary dedicated device or it may be a user equipment that aggregates data from neighboring MTC devices. The MTC devices are considered to be stationary or very low mobility. Let $\mathcal{A} = A_1, A_2, \ldots A_M$ represent the set of all MTCGs in a cell. The MTC devices can send data to their respective MTCG with fixed payload, P_f, to aggregate. Subsequently, the data is sent to the BS for further processing. The network is assumed to have devices organized in the form of groups or classes.

Definition 1: A class/group of services is described as a collection of MTC devices having similar QoS requirements,

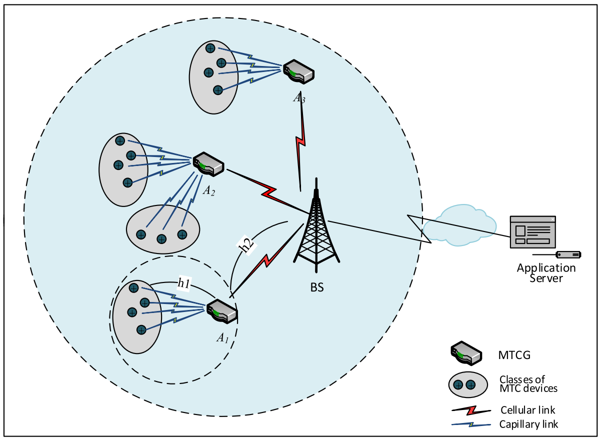

FIGURE 1. System Model.

TABLE 1. Important notations and descriptions.

Symbols	Description
$\mathcal{A}$	Set of all MTCGs
C	Class of services
N	Total number of services
n	Total number of MTC devices in a class
γ_1	received SINR at an MTCG
γ_2	SNR at the BS
ζ_1	intra-frame delay
ζ_2	inter-frame delay
ζ_3	transmission-awaiting MTC devices in a class
ϵ	Minimum threshold wait time under normal priority
$P(c_i m_j)$	final priority of an MTC device

functionalities and same application server. In any class of service, devices work together towards the common goal. Furthermore, data from all devices is required at the application server to make use of it.

Let class of service is represented as C with total number of services as N such that $C = \{c_1, c_2, \ldots, c_N\}$, Let c_1 represents set of MTC devices in a class with n total devices as such that $c_1 = \{m_1, m_2 \ldots, m_N\}$, Thus, all MTC devices T in a network may be symbolized as $T = c_1\, m_1, c_1 m_2, \ldots, c_1\, m_n, c_2\, m_1, \ldots, c_N m_n$.

An MTCG not only serves as aggregator but also resource scheduler [32]. The available resources at MTCG are allocated on the basis of QoS requirements of the MTC devices by implementing the resource allocation algorithm. The communication takes place using cellular and capillary band. Initially, the requests for channel resources is made using capillary band, which actual resources are allocated using cellular band. We assume that the density of MTCGs (λ_{GW}) is more than the density of the BSs, with at least one MTCG ($min(\lambda_{GW} = 1)$) is associated with the BS. For $\lambda_{GW} > 1$, the gateways can access the BS using round-robin approach with work-conserving. Let an average transmit power of an interference source and a device be $P_t^{c_i m_j}$, P_t^I, respectively, the received SINR (γ_1) at an MTCG can be expressed as $\gamma_1 = \frac{P_t^{c_i m_j} K (d_0/d_1)^{\alpha} \sigma_{h1} |H_{h1}|^2}{P_t^I K_I (d_0/d_{I_1})^{\alpha} \sigma_I |H_I|^2 + N_0}$, where $K = (\lambda/4\pi d_0)^2$, $\sigma_{h1} = 10^{-\varphi_{dB}/10}$ and d_0 denotes a constant, shadow fading and a reference distance, respectively. Also, φ and H represents the zero mean Gaussian random variable and the channel coefficient of the desired link, whereas, α and N_0 are the path-loss exponent and the white Gaussian noise power, respectively. Similarly, the SNR at the BS can be calculated as $\gamma_2 = \frac{P_t^{GW} K (d_0/d_2)^{\alpha} \sigma_{h2} |H_{h2}|^2}{N_0}$.

Algorithm 1 Resource Allocation with Dynamic Priorities.

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Initialization:
    Initialize $\zeta_1(c_i m_j) = \zeta_2(c_i m_j) = \zeta_3(c_i m_j) = 0, \kappa = 1$
    An MTC device $c_i m_j \in T$ attempts to sense the medium for availability represented as $\chi_\kappa$

Medium Access:
while ($\chi_\kappa == busy$) do
    Calculate intra-frame wait: $\zeta_1(c_i m_j) = \frac{\chi_\kappa}{\upsilon} \forall c_i m_j \in T$
    Wait for $\zeta_1(c_i m_j) * \mu$ amount of time
    Increment $\kappa$ and sense the medium
    if ($\chi_\kappa \neq busy$) then
        Calculate inter-frame wait time using $\zeta_2(c_i m_j) = \frac{g}{a+g}$
        Calculate transmission-awaiting MTC devices' in a class
            as $\zeta_3(c_i m_j) = \left(\frac{|S_{c_i}|}{|c_i|}\right) \forall c_i \in C$
        Calculate final priority
            $P(c_i m_j) = G_1\left(\zeta_1(c_i m_j), \zeta_2(c_i m_j), \zeta_3(c_i m_j)\right)$
        Wait for $\left((1 - P(c_i m_j)) \cdot \epsilon\right)$ amount of time and sense the medium
        Transmit the request if idle
    end if
end while

Resource Allocation:
With $q$ transmission requests received from the MTC network, an MTCG subsequently demands for resources from a BS
A BS grants $r$ resources subject to availability
if $q > r$ then
    An MTCG calculates
        $\hat{P}(c_i m_j) = G_2\left(\gamma_{c_i m_j}, D(c_i), \omega(c_i)\right)$
    Place all calculated priorities in set $P_\mathcal{T}$ in descending order
    Channel assignment to first $r$ MTC devices in $P_\mathcal{T}$
else
    An MTCG chooses $r$ channels and allocates to $q$ MTC devices, randomly
end if

Transmission Phase:
All MTC devices wait for their allocated channel
Transmit data to gateway
```

III. DYNAMIC PRIORITY-BASED RESOURCE ALLOCATION

This section perspicaciously explains the proposed algorithm. There are two main parts of the proposed algorithm namely medium access and resource allocation.

A. PROPOSED SCHEDULING SCHEME: MEDIUM ACCESS

As explained in the system model, MTC devices are treated as classes with distinct QoS requirements. In such scenarios, devices can leverage a spatial domain to prioritized their transmission [22]. The medium access phase of the proposed algorithm uses prioritized contention using three parameters, 1) intra-frame delay(ζ_1), 2) inter-frame delay (ζ_2), and 3) transmission-awaiting MTC devices in a class (ζ_3). The intra-frame wait is defined as the amount of time induced within a single frame waiting for the transmission medium to be idle. If an MTC device is unsuccessful in capturing the medium in a current frame, then its waiting time is calculated using inter-frame delay. Since MTC devices are working in groups towards a common goal, it necessitates the reception of data from all MTC devices in a class at an application server. Therefore, the transmission-awaiting MTC devices in a class are also used as a priority metric.

Algorithm 1 shows the proposed resource allocation scheme. Initially, all MTC devices share the same priority. When an MTC device wants to transmit its data to an MTCG, it first senses the medium to check availability (represented as χ_κ). If the medium is already taken then the MTC device waits for a random amount of time subject to its ζ_1 before sensing the medium again. While waiting due to the busy medium, every attempt of an MTC device to sense the medium for idleness gradually increases its priority and subsequently reduces the duration of wait time. This is imperative to maintain a long term fairness. An intra-frame delay ζ_1 of an MTC device $c_i m_j \in T$ can be defined as a ratio of the number of attempts to sense the medium for availability to the maximum number of allowable attempts υ. It is represented as;

$$\zeta_1(c_i m_j) = \frac{\sum_{1\leq\kappa\leq\upsilon} \chi_\kappa}{\upsilon}. \tag{1}$$

Note that χ_κ can only be incremented if the medium is found busy by the respective MTC device.

If an MTC device fails to transmit in a frame due to collision at medium access phase or unavailability of resources at allocation phase, it subsequently increases its priority, which is captured as inter-frame delay (ζ_2), which can be calculated as follows;

$$\zeta_2(c_i m_j) = \frac{g}{a+g}, \tag{2}$$

where $g = 1, 2, 3, \ldots$, is the number of frames during which device $c_i m_j$ failed at medium access or allocation phase and $a \geq 1$ is any constant number that controls the priority increment.

The transmission-awaiting quantity of MTC devices in a class/group is captured as ζ_3. The rationale behind using ζ_3 is the fact that MTC devices' data is applicative at the application server unless it is received from all the members of a class. Since MTC devices are working as a group, which tend to be in close proximity [22], [33]. The MTC devices can overhear the access requests of their associated class members and/or feedback acknowledgments from an MTCG. Such MTC devices can maintain S_{c_i} that represent the set of successfully transmitted MTC data in class c_i. The priority-based on ζ_3 of an MTC device $c_i m_j$ can be calculated as

$$\zeta_3(c_i m_j) = \left(\frac{|S_{c_i}|}{|c_i|}\right) \forall\, c_i \in C, \tag{3}$$

where $|*|$ represents the cardinality of the corresponding set.

The final priority P of an MTC device $c_i m_j$ can be calculated as

$$P(c_i m_j) = G_1\left(\zeta_1(c_i m_j), \zeta_2(c_i m_j), \zeta_3(c_i m_j)\right), \tag{4}$$

where G_1 is a multivariate sum function, which can produce a priority value between (0, 1) utilizing weights w_1, w_2 and w_3 of the corresponding variables in Eq. (4). Without loss of generality, we consider $w_1 = w_2 = w_3 = 1/3$ in our implementation. An MTC device's waiting time is contingent to its final priority as $\left((1 - P(c_i m_j)) * \epsilon\right)$ amount of time after the medium is found idle and transmit the data at its expiry. The value of ϵ is the minimum threshold wait time under normal priority to ensure that there is no other imminent transmission request. The value of ϵ depends upon the coverage area of aggregator $R_{A_i} \forall A_i \in \mathcal{A}$. Our model insures the identity of integrity models which keep data secure and trustworthy by protecting system data from intentional or accidental changes. Our model honors all three aspects of integrity models; preventing unauthorized person from making modification, preventing authorized person from improper or unauthorized access, and maintaining consistency of data.

1) SIGNIFICANCE OF ϵ

Under normal priority, all the MTC devices wait for ϵ amount of time after the medium is found idle. Whereas, the MTC devices with a higher priority would wait for a shorter amount of time subject to its priority as $\left((1 - P(c_i m_j)) \cdot \epsilon\right)$. This way, while all the MTC devices may still be waiting for ϵ amount of time after sensing the medium idle, the MTC devices with a higher priority may acquire the medium to send transmission request to an MTCG. This improves the chances of successful transmission of prioritized MTC devices.

2) THE RATIONALE OF ASSIGNING PRIORITY TO DEVICES LIE IN WAIT FOR TRANSMISSION IN A CLASS

In MTC network, usually a group of MTC devices is dedicated to accomplish the same task with certain temporal constraints. Data from the individual MTC devices may not be germane to an application server unless it is received from the whole group. Since random access techniques treat all the MTC devices equally, it is highly probable that

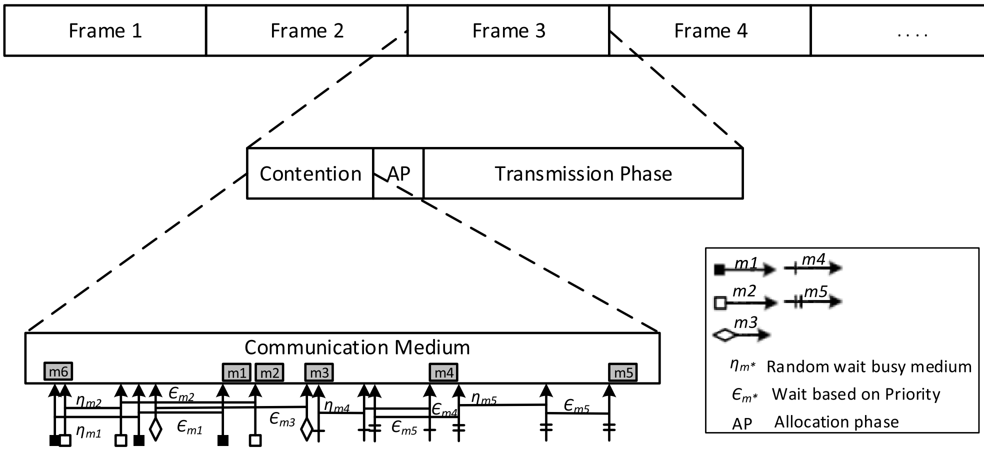

FIGURE 2. **Frame Structure with Proposed Working at Contention Phase.**

a certain MTC application may result in an outage because of the missing data from few MTC devices of the same class. The broadcast nature in wireless communication enables the MTC devices in a group to overhear the transmissions of neighboring devices. Therefore, each MTC device can keep track of number of transmission-awaiting MTC devices in a class to calculate its priority. In this way, as the remaining number of MTC devices in a class decreases, the priority of transmission-awaiting devices increases so do the chances of successful transmission. This will significantly reduce the class-wise average communication delay of MTC devices, which subsequently improves the successful accomplishment of the time-constraint MTC transmissions.

3) FRAME STRUCTURE WITH EXAMPLE OF PRIORITIZED MEDIUM ACCESS

In order to clearly explain the working and significance of intra-frame delay, an example using the analogy of CSMA/CA frames structure is provided. It is worth mentioning that CSMA/CA protocol is not considered in this work. However, similar characteristics are considered which are attributed to CSMA/CA. The frame structure is shown in Figure 2, which has three phases namely contention, allocation and transmission. A demonstration of 6 devices ($m1, m2, \ldots, m6$) is shown in the figure to explain the working of prioritized medium access. The priority mechanism shown in Figure 2 has only considered the intra-frame delay. The MTC devices $m1$ and $m2$ try to sense the medium during $m6$'s transmission, which triggers variable busy medium wait times according to their intra-frame wait priorities η_{m*}. At the expiry of their respective wait times, $m1$ and $m2$ wait additionally based on their final priorities (ϵ_{m*}). An MTC device $m3$ senses the medium, while $m1$ and $m2$ are still waiting. Since the medium is found idle, therefore $m3$ only waits for ϵ_{m3} amount of time. Due to the prior wait times of $m1$ and $m2$ their priorities are higher than $m3$, subsequently, their transmissions also precede $m2$'s transmission.[1] This process goes on for all the MTC devices until the end of the contention phase.

TABLE 2. **Table Maintain by an MTCG.**

Class	$\mathbf{T_{class}}$[1]	T_{succ}[2]	T_0[3]
c_1	10	6	150309
c_3	20	3	150502
c_7	13	4	150508
.	.	.	.
.	.	.	.

[1] T_{class}: Total Devices in a class, [2] T_{succ}: Successfully transmitted devices
[3] T_0: Initial time of the arrival of the first device in a respective class

B. PROPOSED SCHEDULING SCHEME: RESOURCE ALLOCATION

After the completion of medium access phase, an MTCG can receive q requests of transmissions from MTC devices with variable QoS requirements. Three metrics are considered to calculate the priority at the allocation phase namely, received SNR $\left(\gamma_{c_i m_j}\right)$, accumulative delay of class $\left(D_{c_i}\right)$ and number of transmission-awaiting devices in a group/class $\left(\omega_{c_i}\right)$. Let the accumulative delay of an MTC group/class is defined as the sum of delays encountered as a result of all MTC successful transmissions in their respective class, The accumulative delay of class $c_i \in C$ is represented as;

$$D_{c_i} = \sum_{j=1}^{n} D_{c_i m_j} \leq D_{th}(c_i), \tag{5}$$

where $D_{c_i m_j}$ represents the delay of MTC device and D_{th} represents delay threshold of the respective MTC class. The contributing factors towards the delay $D_{c_i m_j}$ are;

$$D_{c_i m_j} = d_t + d_p + d_q + d_r + d_{tr}, \tag{6}$$

where, $d_t, d_p, d_q, d_r, d_{tr}$ represent the transmission, propagation, queuing, processing, and re-transmission delays, respectively.

We calculate the accumulative delay of a class c_i using Table 2 as follows;

$$D(c_i) = T_0(c_i) - T_{now}, \tag{7}$$

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[1] The transmission request to an MTCG to acquire the channel.

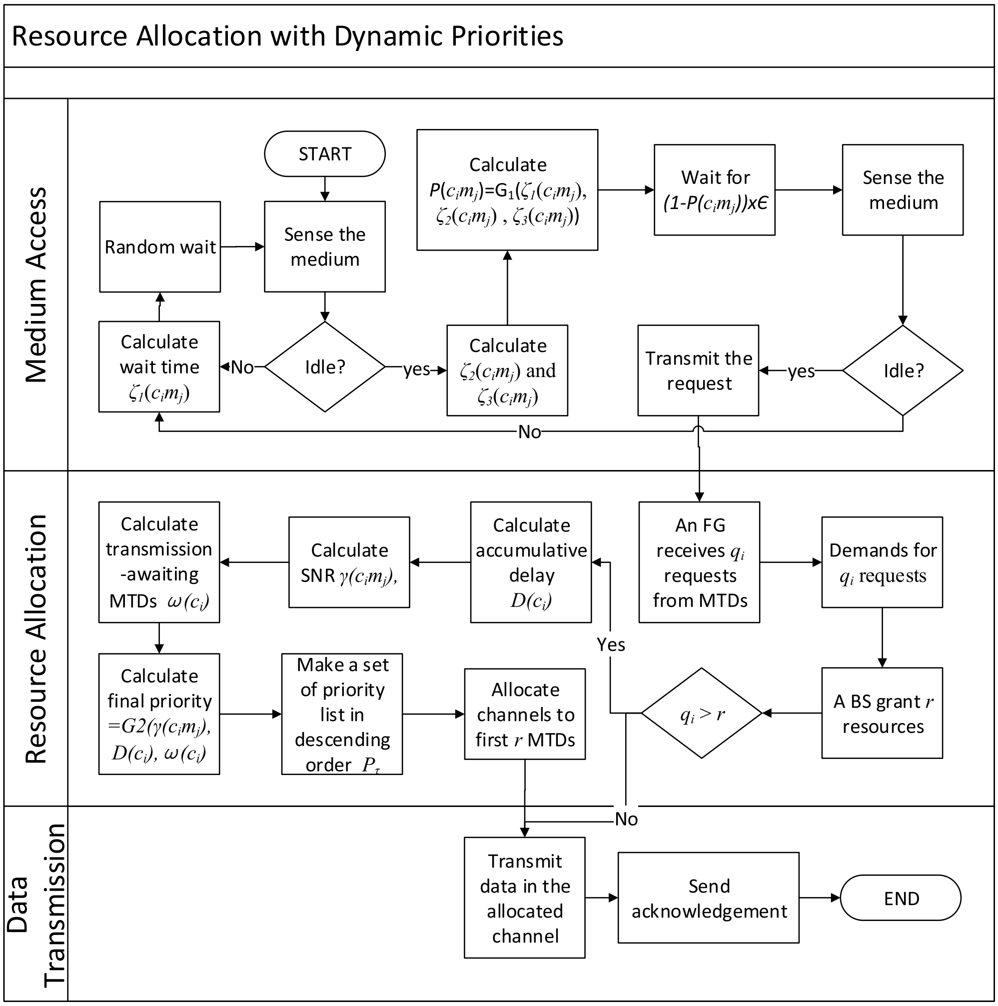

FIGURE 3. Schema of the proposed resource allocation technique.

where $T_0(c_i)$ represents the initial time of the first successful transmission of an MTC device in class c_i and T_{now} is the current time. An MTCG maintains the details as shown in Table 2. The transmission-awaiting MTC devices are identified as;

$$\omega_{c_i} = T_{succ}(c_i) - T_{class}(c_i), \tag{8}$$

where T_{succ} represents MTC devices with successful transmissions. Whereas, the total devices in a group/class c_i are represented as $T_{class}(c_i)$. The final priority of an MTC device $c_i m_j$ is calculated by an MTCG as;

$$\hat{P}(c_i m_j) = G_2\left(\gamma(c_i m_j), D_{c_i}, \omega_{c_i}\right), \tag{9}$$

where G_2 is a multivariate weighted sum function to calculate the priority, $\gamma(c_i m_j)$ is the received SNR of respective device, $D(c_i)$ is the amount of induced delay of a class c_i, and $\omega(c_i)$ represents the transmission-awaiting devices in the class to finish their transmission.

The resource allocation phase of the proposed scheme is shown in Algorithm 1 (line 15-23). Initially, q transmission requests are received by an MTCG at the end of the medium access phase. If q is more than the available resources r, then an MTCG creates a set of priorities $P_{\mathcal{T}}$ comprising MTC devices' priority $\hat{P}(c_i m_j)$ (as calculated in Eq. (9)) in descending order. The available resources r may be assigned to the first q devices in the set $P_{\mathcal{T}}$. However, an MTCG selects a device randomly for the channel allocation in case of a match between total available resources and the transmission requests ($q = r$). In the transmission phase, the MTC devices wait for their corresponding channel resource and transmit the data on their turn.

The overall working of the proposed scheduling scheme is also shown as a cross-sectional flowchart in Figure 3 to improve coherence in understanding its different parts. Various parts of the proposed algorithm are presented along with their functionalities in Figure 3.

C. RATIONALE OF USING JOINT PRIORITIZED MEDIUM ACCESS AND ALLOCATION PHASES

Traditionally, contention-based algorithms are used to access an MTCG to contest for the resources. The MTC devices with heterogeneous QoS requirements necessitate the use of a priority-based resource allocation [19]–[22]. However, at the contention phase of these schemes, where devices try to request for resources, all devices are treated equally despite their variable QoS requirements. The proposed scheduling scheme tries to ensure that devices with higher priority get preferential medium access at the contention phase. To maintain the long term fairness, the wait time of the MTC devices is also utilized in the priority calculation metric. It gradually increases the priority of an MTC device with respect to its waiting time.

Furthermore, the number of devices that successfully passes the contention phase may be greater than the number of available resources. The allocation phase of the algorithm ensures that devices with genuinely high priorities get resources. Since an MTCG can centrally access and manage all the necessary details about the number of service classes, the total number of devices in each class and the number of transmission-awaiting devices, therefore, transmission-awaiting MTC devices in a group/class is reconsidered. In this manner, any imprecision resulted due to hidden node problem at the contention phase may be corrected at the allocation phase. In fact, resource allocation is concerned with the three aspects of security, namely; availability, integrity, and confidentiality. However, all information security measures try to address at least one of these three aspects: preserve the integrity, promote the availability, or protect the confidentiality of data. It is certainly possible to adapt our model to address all these critical security concerns that are crucial to the functionality of the system.

IV. PERFORMANCE ANALYSIS

A. PERFORMANCE METRICS AND CALCULATIONS

In order to evaluate the proposed scheduling and aggregation schemes, success and outage probability analysis are employed.

1) SUCCESS PROBABILITY

The success probability of an MTC device is termed as a successful reception of data at the BS. Based on our system model, an MTC device's transmission can be designated as successful if and only if:

- An MTC device successfully passes the contention phase with no collision.
- An MTC device is granted with channel resources by an aggregator subject to its priority.
- An aggregator successfully transmits the received data of MTC device to a BS.

An MTC device's success probability can be calculated as;

$$\bar{P_s} = \bar{P_{s_1}} \times \bar{P_{s_2}} \times \bar{P_{s_3}}, \tag{10}$$

where, $\bar{P_{s_1}}$ is the average probability that an MTC device passes the contention phase, $\bar{P_{s_2}}$ is the probability that a channel is allocated to that MTC device depending upon its priority, and $\bar{P_{s_3}}$ is the average success probability that an aggregator is not in the channel outage.

Average number of successful MTC devices can be expressed as;

$$T_{succ} = \sum_{k_1=1}^{T} k_1 Pr(K_1 = k_1) P_{s_3}(k_1), \tag{11}$$

Here, K_1 is the number of served MTC devices whose data is successfully aggregated at an aggregator, $Pr(K_1 = k_1)$ is the corresponding probability mass function, and $P_{s_3}(k_1)$ is the conditional success probability of an aggregator given k_1 channels to be served.

The number of MTC devices to be served follow a Poisson Point Process with mean $\bar{m}$ i.e. $Pr(K = k) = \frac{1}{k!}\bar{m}^k exp(-\bar{m})$. The average probability of MTC device passes the contention phase can be represented as

$$\bar{P_{s_1}} = p_{c_i m_j} \frac{exp(-\bar{m} p_{c_i m_j}) - exp(-\bar{m})}{1 - p_{c_i m_j}} \quad \forall c_i m_j \in T, \tag{12}$$

for an MTC device, $p_{c_i m_j}$ is the probability of $c_i m_j$ passing the contention phase, which can be calculated using its priority metrics. Given k MTC devices under an aggregator serving zone, the probability that an MTC device selects a non-collided MTC device is $(1 - p_{c_i m_j})^{k-1}$. Hence, the average successful probability at the contention phase can be represented as;

$$\begin{aligned} \bar{P_{s_1}} &= \sum_{k=1}^{T} p_{c_i m_j} (1 - p_{c_i m_j})^{k-1} Pr(K = k) \\ &= p_{c_i m_j} \frac{exp(-\bar{m} p_{c_i m_j})}{1 - p_{c_i m_j}} \\ &\quad \times \sum_{k=1}^{T} (1 - p_{c_i m_j})^k \bar{m}^k \frac{exp(-\bar{m} + \bar{m} p_{c_i m_j})}{k!} \\ &= p_{c_i m_j} \frac{exp(-\bar{m} p_{c_i m_j})}{1 - p_{c_i m_j}} \left(1 - exp(-\bar{m} + \bar{m} p_{c_i m_j})\right). \end{aligned} \tag{13}$$

We considered the number T to ∞ to approximate $\left(1 - exp(-\bar{m} + \bar{m} p_{c_i m_j})\right)$ as:

$$\begin{aligned} &\sum_{k=0}^{\infty} (\bar{m} - \bar{m} p_{c_i m_j})^k \frac{exp(-\bar{m} + \bar{m} p_{c_i m_j})}{k!} = 1 \\ &\quad = exp(-\bar{m} + \bar{m} p_{c_i m_j}) \\ &\qquad + \sum_{k=1}^{\infty} (\bar{m} - \bar{m} p_{c_i m_j})^k \frac{exp(-\bar{m} + \bar{m} p_{c_i m_j})}{k!}. \end{aligned} \tag{14}$$

After an MTC device gets successful in passing through the contention phase, it needs to be granted the channel resource. The probability $\bar{P_{s_2}}$ that it will be granted a resource can be calculated as

$$\bar{P_{s_2}} = Pr(\Upsilon) \cdot Pr(\gamma_{c_i m_j} > \gamma_{th}) \cdot Pr(\zeta), \tag{15}$$

where $Pr(\Upsilon)$ is the probability of available channel resource for an MTC device subject to passing the contention phase, $Pr(\gamma_{c_i m_j} > \gamma_{th})$ represents the probability that the received SINR of an MTC device is greater than a threshold value, and $Pr(\zeta)$ represents the probability of transmission-awaiting devices of an MTC device's class to be greater than the rest of the classes. With q available resources, the probability that an MTC device passes through the contention phase and be granted a resource is $\frac{P_{s_1}}{q}$. Similarly, for known transmission-awaiting devices in the class $w(c_i)$, $Pr\left(1-\frac{w(c_i)}{|c_i|}\right) > \left(1-\frac{w(c_j)}{|c_j|}\right) \forall j \neq i, j = \{1, 2, .., N\}$ can be used.

The $Pr(\gamma_{c_i m_j})$ is estimated as follows;

$$Pr(\gamma_{c_i m_j}) = Pr\left(\frac{y_{c_i m_j}}{\sum_{x \subset \Phi_{MTC}^{int}} y_I d_I^{\alpha} x^{-\alpha}} > \gamma_{th}\right), \tag{16}$$

where $y_{c_i m_j}$ denotes fading power gain on the desired link of an MTC device at distance d_1 following gamma distribution, y_I represents fading power gain on interfering link following exponential distribution, d_I is the distance between MTC and its serving aggregator, γ_{th} represents the threshold SINR and x represents both the location and interfering MTC device that occupies a certain channel. Using [20] the probability of received SINR of an MTC device can be calculated as

$$Pr(\gamma_{c_i m_j}) = exp\left(-\lambda_{MTCG}\pi\frac{R_s^2}{2}f(\alpha)\right) \tag{17}$$

where λ_{MTCG} is the density of aggregators, R_s is the radius of the serving zone of the aggregator, while $f(\alpha)$ is defined as

$$f(\alpha) = \Gamma\left[1+\frac{2}{|\alpha|}\right]\Gamma\left[1-\frac{2}{|\alpha|}\right]\gamma_{th}^{\frac{2}{|\alpha|}} \tag{18}$$

where Γ is the gamma function. Interested readers are referred to [20] for the proof.

The average success probability of an aggregator working in round-robin fashion results in noise limited scenario and can be calculated as

$$DK_1 \leq TWlog()1 + y_{MTCG}, \tag{19}$$

where D is the data size, K_1 is the number of served MTC devices by an aggregators, T is the transmission time, W is the available bandwidth and y_{MTCG} is the desired signal of an aggregator. A BS can successfully receive aggregated data from an aggregator provided its SINR meets the following

$$\bar{P_{s_3}} = E_{K_1}\left\{Pr\left(y_{MTCG} \geq 2^{\frac{DK_1}{TW}}\right)\right\}, \tag{20}$$

B. SIMULATION RESULTS

In this subsection, the proposed scheduling technique is evaluated by comparing it with the existing schemes. The simulation parameters are shown in Table 3 [19], [20]. The Simulation environment is implemented using Matlab.

TABLE 3. Simulation Parameters.

Parameter	Values
Bandwidth of channel	180kHz
Size of packet	64kb
Reference distance d_0	1 m
Energy utilization per packet	50J/d_0
Number of MGs randomly distributed	4
UE speed	1-3m/sec
Maximum MTC device-MG distance ($d1$)	15 m
Maximum MG-MTCG distance ($d2$)	25m
Maximum MTCG-BS distance ($d3$)	200m
Maximum MTC-MTCG distance	25m
Time interval for sending data ($\mathcal{T}$)	5 sec

The outage probability of the proposed resource allocation schemes is shown in Figure 4. The outage is calculated on the basis of threshold allowed service time for a class of devices. As the number of devices increases, the outage of the random resource allocation technique degrades significantly as compared to others. In addition, like random resource allocation, RSS based technique performs better initially. This is because initially the impact of priority-based on classes is not significant. However, as the number of devices increases, the performance of RSS based resource allocation degrades significantly. The proposed dynamic resource allocation algorithm (Algorithm 1) performs better by giving priority-based on parameters such as transmission-awaiting devices in a class, queuing delay and QoS requirements. The existing algorithm does not consider the prioritized contention phase as compared to our proposed improved resource allocation. We can see that by giving priority at the contention phase significantly improves the outage probability. Since, MTC devices work in groups, considering transmission-awaiting devices in the class at contention and allocation phases improves the outage by giving more priority to the remaining number of devices in a class.

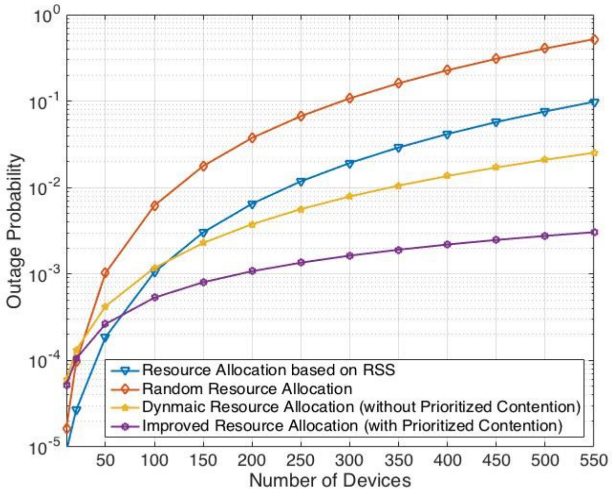

FIGURE 4. Outage probability of dynamic resource allocation and improved resource allocation with increasing devices' density.

The success probability of the proposed algorithm with increasing number of MTC devices is shown in Figure 5. A total of 50 classes with a constant class size of 20 is considered. A success is defined as the number of classes that complete their transmission. It can be seen that the probability of success is not significantly different for a small number of MTC devices. However, as the number of devices increases,

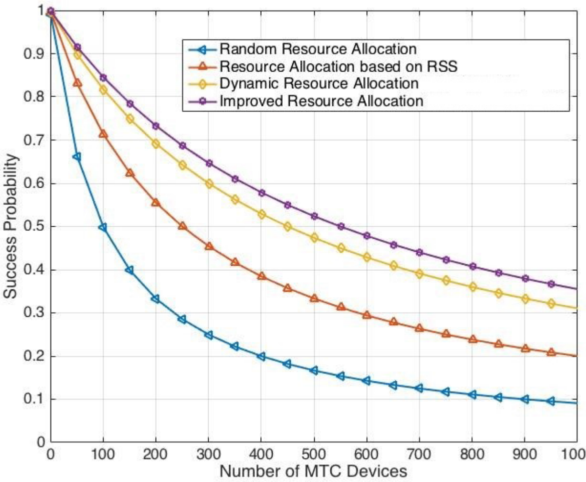

FIGURE 5. **Success Probability of the proposed algorithm with increasing number of MTC devices.**

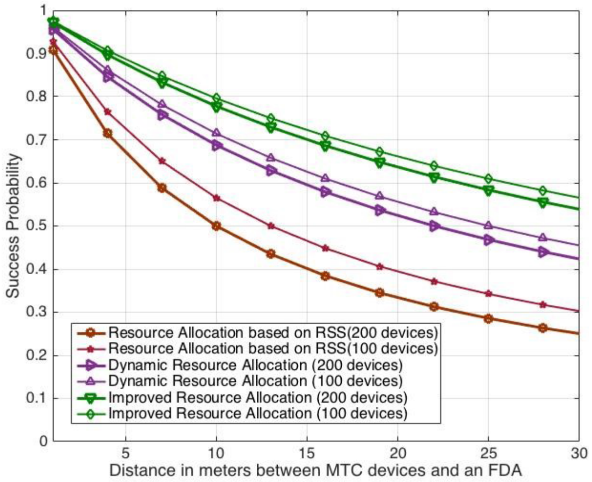

FIGURE 6. **Success probability of proposed algorithm with increasing inter MTC-MTCG distance.**

the probability of success greatly decreases. Since random resource allocation assigns resources to devices irrespective of their classes, the success probability is the worst. Resource allocation based on RSS [19], [20] improves the result as compared to random resource allocation. This is because MTC devices in close proximity tend to have comparable SNRs and therefore implicitly favor the completion of transmission in a class and improves the success probability. The proposed algorithm (with and without prioritized contention) explicitly consider the classes and assign priority on the basis of it. Therefore, we can see that they improves the overall success probability.

The success probability with increasing distance between MTC devices and MTCG is shown in Figure 6. Devices density of 100 and 200 is considered for the simulations. The proposed schemes (with and without prioritized contention) is compared to the RSS based schemes in [19], [20]. We can see that as the distance between MTC devices and MTCG increases, the performance of RSS based schemes degrades significantly due to the sole reliability on SNR. The proposed schemes perform better due to its multi-fold parameters consideration. The proposed schemes do not solely depend upon SNR but also factors such as QoS requirements, transmission-awaiting MTC devices in a class and queuing delay, which dynamically stint on the priority metrics to reduce the impact of SNR.

V. CONCLUSION

Resource allocation has always been a serious challenge in wireless communications. This paper proposed a secure and integral scheduling scheme that comprised of medium access and resource allocation phases. The proposed scheme leveraged the class-based working mechanism of MTC devices to assign priorities and improves the overall success probability. Unlike existing work that considered a random access mechanism at the contention phase, we considered a prioritized contention mechanism with the provision of transmission-awaiting MTC devices in a class along with intra and inter frame wait times. In addition, the resource allocation phase considered MTC devices' SNR, total induced delay, and pending number of MTC devices in a class. This ruminated consideration brought improved success and outage probability as compared to the schemes based on mere received SNR.

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