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Energy Efficient Uplink MAC Protocol for M2M Devices

ANUM ALI[1], GHALIB A. SHAH[2], AND MUHAMMAD SHOAIB[1]
[1]Department of Computer Science, University of Engineering and Technology, Lahore 54890, Pakistan
[2]Sultan Quboos IT Chair, University of Engineering and Technology, Lahore 54890, Pakistan

Corresponding author: Anum Ali (anum.ali@live.com)

ABSTRACT To enable connectivity between a massive number of devices on the Internet of Things (IoT) paradigm, machine-to-machine (M2M) communication is implied. The key feature of emerging and ad hoc networks, such as M2M communication, is a low-complexity medium access protocol. In this paper, an uplink centric simple approach is proposed that aims to improve the energy efficiency of the devices of M2M communication. To facilitate the requirements of these networks with a massive number of ubiquitous devices, the current version of slotted aloha is optimized specifically for M2M architecture. To reduce complexity, this paper does not change the architecture but, additionally, add a simplified approach to gain efficiency. Previous slotted aloha protocols work well under less traffic but in the case of M2M architecture, it may become a bottleneck. The proposed power adaptive technique adjusts the delay time for transmission slots mainly for small sensor devices used in M2M applications, such as health care, weather trackers, and other delays sensitive M2M applications. An improvement in energy efficiency was achieved by increasing the energy efficiency at 60% rate compared with other techniques and lifetime to 45% while keeping the throughput steady and reducing the time and space complexity. The results are simulated in MATLAB. Better message delivery was achieved by considering the power profiles of M2M devices.

INDEX TERMS Machine-to-machine, power adaptive, MAC, slotted aloha.

I. INTRODUCTION

Machine-to-machine (M2M) network consists of numerous small powered devices communicating through mostly a single medium (channel) [1]. The data is small in chunks and usually in periodic form [2]. Since these devices cannot afford a lot of power consumption for transmission therefore there exists a necessity for upgrading the current version of MAC protocol. In 5G systems, machine-type communication (MTC) is expected to play vital role [3]. MTC is further classified as ultra-reliable MTC (uMTC) which is concerned with availability, high reliability and latency. Where massive MTC (mMTC) is about providing connectivity to massive number of devices whose communication is based on short packets. mMTC main focus is on uplink communication of massive number of small low powered devices. This involves completely different technologies as compared to human-to-human communication mainly used in cellular and LTE networks. For facilitating uplink centric communication certain questions should be solved. 1) How much energy efficient enabled are MTC devices through MAC technologies. 2) Is grant-based or grant-free access control better suitable. and 3) Whether non-orthogonal or orthogonal medium access is better. Uplink data which is received at M2M server through aggregators is heterogeneous consisting of certain measures such as payload size, packet delay and arrival rate. These all factors affect message transfer rate and may cause a device to suffer delay which require power consumption. For transferring message through uplink channel may experience small or large contention window. Increasing contention window time may increase latency and for power saving issue this become a problem. Especially when uplink packets are given equal chances to reach destination. To improve energy efficiency, researches have shown results but still there are many concern related to it since mostly the techniques cater the downlink issues. Uplink transmission is usually schedule by eNB node through request-grant procedure. It lasts around 5 or 10 ms or longer delay which is disadvantageous for delay sensitive traffic. The latest research [4] proposes a hybrid-mac technique for achieving efficiency. Although the paper claims to achieve 41% improvement but it does produces a lot of complexity

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as it design new architecture and introduces stations. Previous techniques [5] either put the device into sleep mode or create cluster to handle energy efficiency solution. Many standardization companies such as Internet Engineering Task Force (IETF), International Organization for Standardization (ISO), and Institute of Electrical and Electronics Engineers (IEEE) have proposed protocols at stack layer but energy efficiency features are still unsatisfactory.

To support M2M communications various new communication technologies have been considered. The MAC protocols involved in these communication implementations are nowadays mainly hybrid based combining schedule and contention based mechanism. This may give advantage but it increases the complexity. In market there are many variations of CSMA and Aloha, which are mainly used. Our main concern is with Aloha variations since it is related sensor networks as mentioned earlier. According to which the used MAC protocols are discussed below based on the M2M networks.

1) *M2M cellular network:* This fixed but ubiquitous network provides many benefits regarding mobility support and coverage etc. By cellular IoT we refer to Long Term Evolution for Machines (LTE-M) and nowadays towards 5G. Usually in this setup contention based MAC protocols are used but new research also applies contention free techniques [6]. Communication between devices and eNB is based on Frame Slotted Aloha (FSA) MAC protocol.
2) *Narrowband IoT:* To facilitate the heterogeneous needs of M2M communication, a Narrowband IoT (NB-IoT) radio access technology is introduced. NB-IoT is capable of working in-band or using dedicated frequency resources. NB-IoT uses overlaid Code Division Multiple Access (CDMA). Currently many other techniques are underway for a modified random access scheme that results in a fast development time [7].

A. CURRENT ADOPTED TECHNIQUES

A proper study exists [8]–[10] regarding the different classes of MAC protocols. MAC protocols those are contention free such as Code-division multiple access (CDMA), Time-division multiple access (TDMA) and Frequency division multiple access (FDMA) protocols cannot offer high throughput to full fill the demands of sensor like devices involved in Internet-of-Things (IoT) network [11]. Due to unused empty slots and overhead therefore they are unsuitable. Where as contention based MAC protocols like Carrier-sense multiple access with collision avoidance (CSMA/CA) is suitable for small networks and cannot serve ubiquitous devices. For sensors mainly two types of medium access control (MAC) protocols exists for facilitating sensors nodes access to channel. Those MAC protocols are ALOHA [12] and Random Slotted ALOHA. Among the other random MAC protocols for wireless sensor systems, ALOHA with its modified versions are been usually deployed for many wireless networks. Slotted aloha optimizes Aloha and eliminates collisions occurring

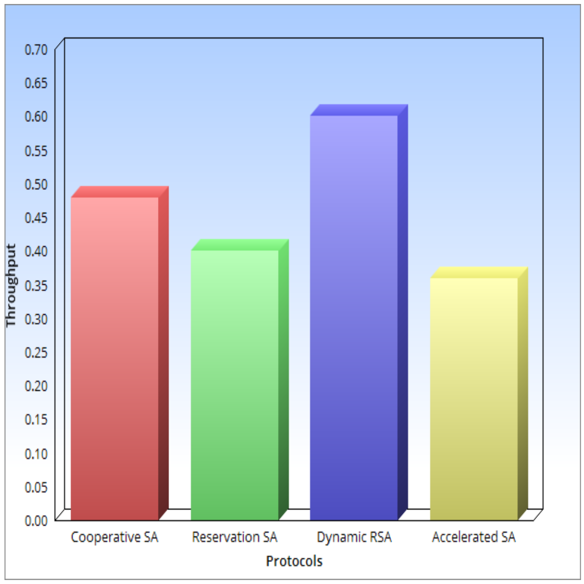

FIGURE 1. Variations of Slotted Aloha for IoT.

during transmission. Slotted ALOHA is an old protocol belonging from random access protocols, the protocol behavior is autonomous, best for IoT network. For accommodating the needs of M2M architecture, current protocol should be optimized for incorporating requirements. One of those crucial requirement is energy efficiency [5]. Since this research work targets M2M network therefore our considered MAC protocol is Slotted ALOHA. Due to power restrictions in IoT network, the current version of Slotted ALOHA design is not feasible. Until now many studies have investigated to improve the throughput of Slotted ALOHA [12], [13]. A novel MAC protocol should have high throughput, energy efficiency and should be scalable. This MAC protocol should also show low complexity requirement for IoT network. Fig. 1 presents comparison of different variations of customized Slotted Aloha protocol through different techniques for M2M communication network. The graph includes Cooperative SA [14] has illustrated a throughput of 48 %, Reservation based Slotted Aloha [15] shows a comparatively less throughput ranging to 40% where as the protocol second version Dynamic RSA [16] illustrates much better throughput of 60%. A event driven version of Slotted Aloha termed as Accelerated Slotted Aloha [17] achieves only 36% of throughput although the protocol does conserve time.

B. RELATED WORK

A limited work is available regarding to achieve energy efficiency for uplink centric MAC protocol for M2M. Following previous works are summarized in Table 1, [18] literature work presents an energy efficient MAC protocol that is in two steps, step one adapts contention and reservation-based protocols based on cellular networks for M2M communications and step two proposes partial clustering to handle the massive access problem in ubiquitous devices. The results shows reduced delay. The paper [19] proposes a new random

TABLE 1. Energy efficient M2M MAC protocols.

MAC Protocol	Application	Complexity	Energy Efficiency
Cellular Network [19]	Industrial	O(n)	12%
Adaptive Aloha [20]	RFID	O(n^c) where 0 <c <1	19.5%
Mac FESM [21]	Farming	O(n^2)	30%
Mac Clustering [22]	Surveillance	O(n^2)	5%
SS-M2M [23]	Monitoring	O(n^2)	25%
Mac duty-cycling [24]	Routing Role	O(n^2)	61%

multiple access (MAC) protocol to improve the system efficiency by resolving collisions in the received signal. In this work, the authors consider one of such protocol, called frameless ALOHA, and propose two techniques to improve the energy efficiency without sacrificing the network throughput. In addition, the authors more specifically propose mechanisms to adaptively control the access probability of the users. The proposed techniques were local and similar to the original frameless ALOHA, there is no necessity of coordination between the users. The results depicts an improvement in the energy efficiency through the proposed techniques. Further the paper [20] discusses a selected set of 802.11ah MAC features and proposes an optimized main perspective of energy utilization. In this work the authors proposes a new energy-saving mode, termed as FESM. The simulation were carried out with a system-level MAC simulator while using an uplink scenario with sporadic data traffic elaborating different M2M use cases such as, the farming scenario illustrating the energy harvesting potential. The literature work [21] deals with updating the M2M networks hierarchy, structured to accommodate efficient data transmission between terminal nodes and sink node while using cluster heads. The authors have proposed a medium access control (MAC) protocol, targeting specifically to backoff time decision rule, fit for hierarchy M2M networks. The protocol states to have achieves analytical success probability in channel access by cluster heads and results are compared in simulation. The results shows a reduced per-node energy consumption in comparison with well-known MAC protocols, the Sensor Medium Access Control Protocol (SMAC) and the Directional Medium Access Control Protocol (DMAC) algorithms specifically for sensor networks. The literature work [22] proposes Smart Sleep M2M (SS-M2M) protocol in order to effectively improve the energy utilization in each M2M node. The protocol at sink updates mobility which have been concerned to implicit provide load balancing and reduce the end-to-end delay. The protocol have been simulated using MATLAB and the results showed an enhancements of the proposed approach in terms of packet delivery at the base station and network lifetime, the authors state that SS-M2M protocol extends the network lifetime by 78% with compared to three previous algorithms. The results also shows to increase the packets transmission to sink nodes by 82%. The paper [23] aim at providing each node a specific sleep-depth, according to criteria mentioned during the deployment phase such as applicative criteria or location in the routing structure. The idea is implemented over Iot SensLab testbed. In this protocol the nodes are divided into disjoint subsets, each have different given duty-cycle configuration which leads to a network performance managed to achieve its best performance in terms of loss of rate, delays and energy consumption. The authors explains how their work preserves network connectivity with coherent heterogeneous duty-cycling, thereby reaching a compromise between reactivity and energy consumption. The experiment demonstrates that the solutions preserve the loss-rate below 10%, provide up to 61% energy saving, and guarantee the connectivity of the network. In the literature work [4] proposes an architecture for Long Term Evolution-Advanced (LTE-A) cellular network and aims to reduce the signaling overhead over devices. The authors state that this architecture forwards messages to BS and reduce time delay which enhances energy efficiency of the devices. The paper claims to achieve 15% better energy efficiency with comparison to heuristic algorithm.

There still are many problems with current available schemes in literature such as some algorithms induces much of time delay for uplink transfer and some strategies are complex to implement. There is a wide gap present for effective energy efficient scheme specific for M2M devices MAC design. This paper investigates and simulates power adaptive technique thereby optimizing the current version of Slotted Aloha for uplink communication. Our investigation leads to following contribution and observations.

- This paper is about modeling an uplink centric energy efficient MAC protocol that optimizes MAC protocol with respect to IoT devices. The paper does not alter the main protocol but a simplified computation changes the delay time and adjusts the contention window size for low powered devices. Hence this does not require additional changes in system but also reduces the complexity.
- Proposes strategy to reduce delay constraint and achieve increased lifetime and energy efficiency without changing the throughput infact increase the transmission rate.
- In addition, the second phase of the paper give an optimized approach for selection of low powered devices at base station (eNB) for giving priority slots on spectrum during transmission. The proposed approach keeps the throughput same but maximize energy efficiency for M2M devices. The device has the same access probability at each contention round but increases efficient use of the power of devices by altering the interval between contention rounds. This increases the chance of messages to be sent according to the device power. Since IoT device power consumption is restrained therefore traditional MAC protocol should be updated for giving privilege to low powered devices. Slotted Aloha is the best performance protocol for wireless sensors network. It is random and has autonomous behavior best suited for low powered devices.

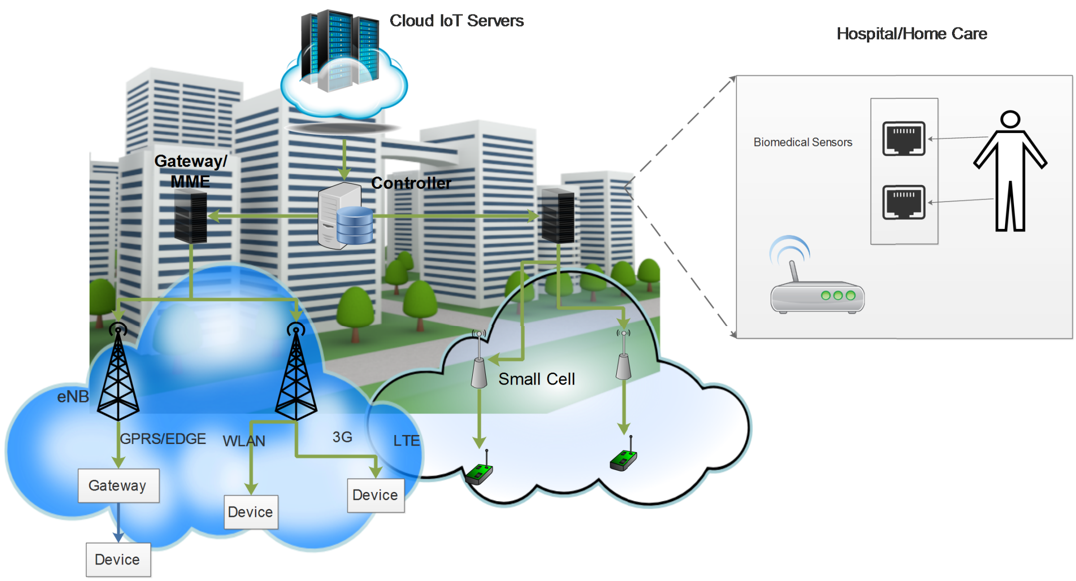

FIGURE 2. System model.

The rest of the paper is organized as follows: Section II elaborates system model and problem formulation. The solution is proposed in Section III. Simulation and results are discussed in Section IV, followed by Section V conclusion which concludes the paper.

II. SYSTEM MODEL

Our system consists a number of small powered nodes sharing single medium, shown in Fig. 2. Our approach targets low power sensors such as biomedical sensors. In the paper, nodes are represented as M_i where $i\epsilon 1, 2, \ldots .k$. k is the maximum number of devices. Considering that nodes are always ready for transmission and acquire frames of slotted aloha. Here in our system opposed to original Slotted Aloha protocol, time slots might not be in equal intervals. The length of a time slot is equal to time needed to transmit a packet and a guard time for propagation delay. The device transmission is first modeled. In our system a device wants to send data, U_i to base station using slotted aloha contention round. The signal received is in time slot x of eNB contention round and is termed as $S(x)$, as shown in following equation.

$$S(x) = \sum_{i=1}^{k} z_i(x)U_i \quad \forall x \in X \tag{1}$$

Here z_i is a Bernoulli variable used to indicate whether device has transmitted in a specific time slot x or not, for example $z_i(x) = 1$ if data is successfully transmitted and $z_i(x) = 0$ if the transmission is not successful. Moreover $x \cong 1, 2, 3, \ldots X$. According to above description it can be termed as following equation.

$$Y[z_i(x) = 1] = y_i(x) \quad \forall i \in k, x \in X \tag{2}$$

Here $Y[.]$ is termed as probability of an independent event. Probability of successful transmission is further described. After receiving the signal $S(x)$, the base station executes protocol on $S(x)$ including all received signals to resolve packets. For slot size $= \delta$ computed from proposed algorithm, assuming average packet generation rate from all devices is Π. The average packet arriving in slot x is given by $G = \delta \times \varpi$. The arrival rate is Poisson described next section.Ten the upper bound throughput is shown in below equation.

$$\Theta = 1 - \exp(-G) \tag{3}$$

where Θ_{max} is instantaneous throughput. Throughput is 1 if there are large values of G and shows the spectrum is fully utilized.

A. POISSON DISTRIBUTION

To test a transmission scenario, packets can be generated based on Poisson distribution. Poisson distribution is usually used in trafficking wireless communication [24]. Below is the equation for calculating Poisson arrival 4.

$$A\left\{N(I) = n\right\} = \frac{(\lambda \times I)^n}{n!} \times e^{-\lambda \times I} \tag{4}$$

Here number of packets are denoted by $N(I)$ are generated in finite time intervals denoted by I following the Poisson distribution based on the parameter λ, which is expected number of arrivals per unit time. The generated packets are buffered until the first transmission opportunity comes in the simulation. In old version of Slotted Aloha, arrival of packets are buffered and if collision occurs then the data is removed from the buffer if retransmission fails more than thrice.

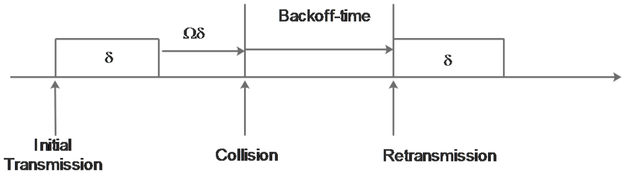

FIGURE 3. Backoff margin in system model.

B. BACKOFF-TIME RULE

A device having to transmit data when channel is idle can face random backoff time, Fig. 3 illustrate the concept where δ represents the contention window size that adjusts according to power of device and delay time. For calculating the backoff-time $backoff_{time}$ in M2M communication through following equation 5.

$$backoff_{time} = \lfloor \frac{2^l}{R_{agg}} \times ran() \rfloor \times backoff\_time\_slot \quad (5)$$

where R_{agg} is aggregate function. Aggregate is proportional to amount of data, l is non-negative variable. Initial value is set and incremented by one value per backoff until reaches maximum value. $ran()$ is random function having uniform distributed value. Backoff time variations were discussed in [25]. It also depends on type of data and message length [26].

Since our focus is on small devices related to health care those who cannot afford a lot of power consumption therefore probability of transmission should be calculated [27]. The probability of successful transmission q_s can be expressed as 6, in which each packet has q probability to reach destination [28].

$$q_s = kq(1-q)^{k-1} \quad (6)$$

where k are the number of devices. Similarly the collision probability is computed in equation 7.

$$q_c = 1 - \left(1 - q \times \frac{1}{CW}\right)^{k-1} \quad (7)$$

where we have assumed that $k \geq 1$ and CW represents contention window.

III. A SIMPLE APPROACH: ENERGY EFFICIENT UPLINK MAC PROTOCOL

In this section, proposed MAC protocol is described for machine type access to channel. Here assuming that a dedicated channel is provided for M2M communications. The communication is in a cell between machines and serving base station. In this scenario, only uplink communication is considered on which we implement proposed MAC protocol. The transmission is organized in slots. Each device generates one or zero data messages based on Bernoulli variable, described further in the section. The generated message has to be transmitted during the current slot or it is discarded. This type of approach conserves the energy for message delivery of the devices by either limiting the message transmission attempts or by reducing the delay time for resending the message.

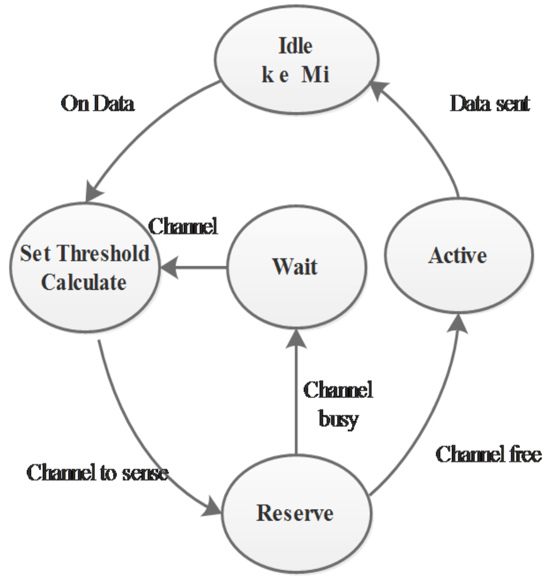

FIGURE 4. State transition diagram.

This section proposes power adaptive methodology. Our methodology is divided into two phases: Phase 1 involves power adaptive Slotted Aloha Mac protocol, in which interval of contention round provided to devices depends on the power constraints of the device, and in Phase 2 the data from devices are provided spectrum based on again the power class to which the device belongs. Both of these techniques improve energy efficiency without compromising the throughput of Random Slotted Aloha. Our techniques benefit from channel usage details. In our system there are two types of statuses that can be defined on devices but the devices passes different transition phases shown in Fig. 4. Those are following.

- Transmission Time: In this period, the successful selected device is allowed to transmit its messages during a reserved time slot. The whole period is divided into slots for the transmission. Each slot can be reserved to any device until time of delivery expires or device has no data to send.
- Contention Time: During the time, the device having traffic to be sent are contended for reserving a time slot in transmission time. This contention is performed through proposed phase 1 algorithm. The device will send a requesting message (REQ) to the eNB. After approval the device is successfully contending the transmission and reserves the time slot. If no collision occurs during transmission, the eNB performs the reservation procedure and determine time slot number of reserved slot. The successful contended device stop sending message to eNB when device receives ACK signal which includes time slot number. In case of collision the device have to retransmit the device data after the delay time calculated by proposed algorithm.

TABLE 2. Device power classes.

Class	Power Range	Domain
A	1-10 dbm	Health
B	11-20 dbm	Agricultural
C	21-30 dbm	Mobile Networks

Since devices are battery powered therefore cannot afford longer wait times. A sensor may be introduced to measure the delay time, if the measured value does not exceed the set threshold then device continue to transmit otherwise it may choose not to generate message. The traffic generated has heterogeneous quality of service (QoS) requirements according to devices power profiles. Table 2 lists the power profiles.

A. PROPOSED TECHNIQUE: POWER ADAPTIVE SLOTTED ALOHA (PASA)

Similar to original Random Slotted Aloha [29], the eNB node sends a beacon message to the devices as indication for the start of a contention round, this is the notification time. In notification time the eNB sends a broadcast message to all devices. This message contains the information for devices for reserving the time slots. To achieve better energy efficiency one way is to ensure that on an average scale devices transmit data with average probabilities as compared to original Slotted Aloha algorithm. This in turn will mean that there will be average number of transmission. For instance we assume that power adaptive proposed algorithm and original Slotted Aloha start with same access probability at the beginning of contention round. Now if proposed scheme tenure have devices scaled to average access probabilities decreases in n, i-e $\bar{p}(n) < \bar{p}(n-1)$, this generates few numbers of transmissions compared to original Slotted Aloha. Similarly here probability analysis is presented and finding a condition to ensure $\bar{p}(n) < \bar{p}(n-1)$. Satisfying this condition while implying fixed step sizes for adjusting probabilities is difficult. For this reason proposed algorithm introduces variable thresholds. For discussion, lets assume at first contention window the probability is $\bar{p}(1)$ and $\bar{p}(2)$ at any such device. And the probability for all devices is P_{total}, therefore at beginning the contention round does not end at the first slot then the next slot have two possible values of probability. Either it is $P_{total} - \aleph k$ or it is $P_{total} + \aleph k$.

The power adaptive MAC protocol which is also based on QoS power profiles of devices provides an estimate of message delay which is used to source transmission whether to make sure that the message delay $\Omega[t_{message}]$ is also supported by the node. Thus the constant of delay can be met accordingly to following condition shown in 8.

$$\frac{\tau}{|P_1|} \geq t_{message} \tag{8}$$

where P_1, route length can be calculated based on device density, maximum distance of a device, advancement a and sink Q by equation 9.

$$|P_1| = \frac{Q}{aP_d\left[\gamma\frac{\pi(d^2-a^2)}{4} \geq 1\right]} \tag{9}$$

Here d^2 represents distance of device. Further by solving, following simplified equation 11 can be obtained through 10.

$$\frac{Q}{a}P_d\left[\Psi\frac{\pi(d^2-a^2)}{4} \geq 1\right] \geq \frac{\tau}{t_{messge}} \tag{10}$$

$$1 - \frac{4d^2}{\Psi(d^2-a^2)} \geq \frac{\tau a}{t_{message}Q} \tag{11}$$

Here τ, a and Q are fixed values, meanwhile $t_{message}$ can be varied dynamically whose value can be calculated from above equation 11. The fraction presented on right-hand side give approximated probability of the delay constraint. For example in this case if an application specifies deadline τ to be too short with respect to $\Omega[t_{message}]$, then the device may experience low probability of achieving the required QoS. Therefore QoS can be supported with probability P shown in following equation 13 through 12.

$$\left(1 - \frac{4d^2}{\Psi(d^2-a^2)}\right) \geq p \tag{12}$$

$$\Psi \geq \frac{4d^2}{(1-p)(d^2-a^2)} \tag{13}$$

In this proposed system model the delay has three components, those are

- The delay occurred due to retransmission.
- The delay during propagation.
- Transmission of packet delay.

Further progressed towards the proposed power adaptive algorithm after calculating delay probability. The generated device message is specific to each system and implied algorithm setting. Previously this message contains the slot number to be reserved by a specific device. But this is not suitable for M2M devices due to energy consumption restrictions. Other low powered devices may suffer during longer delay time. Here the proposed algorithm reduces the delay time. After receiving beacon message, the device starts to send message architecture shown in Fig. 5. Here in this step assuming that through using information from Random-access channel (RACH) or from Power Head Room (PHR) report, the knowledge of transmission power "α" of the device can be obtained. The contention round interval δ can be computed, as shown in algorithm 1. Further on, the algorithm of proposed hypothesis is as following.

The description of the algorithm is as follows, in the first step the power of the device is known from RACH channel. According to the power profile class listed in Table 2, the maximum power limit "θ" is set. The main purpose is to calculate contention window/round interval termed as δ. The computation is performed through equation shown in 4th step of the algorithm. Depending on the δ value the length of the contention window is calculated, shown in equation 14.

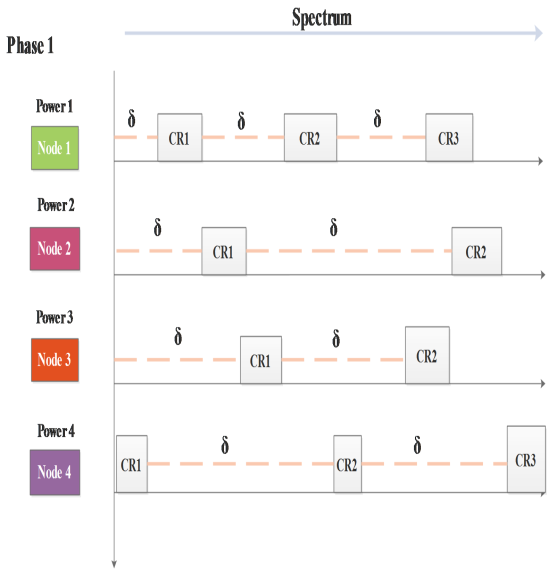

FIGURE 5. Proposed power adaptive algorithm.

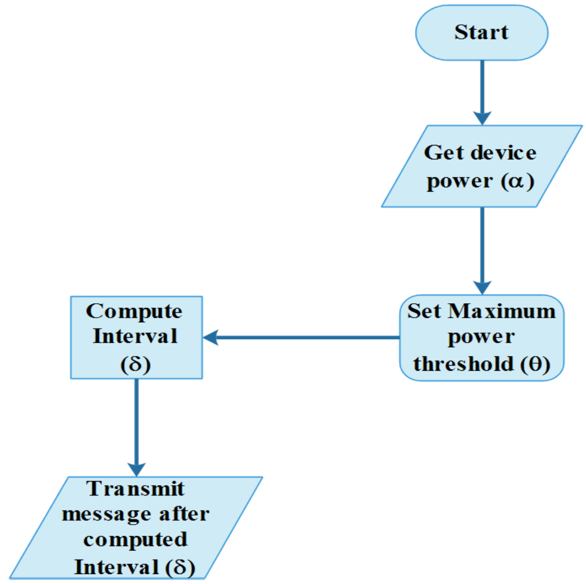

FIGURE 6. Flowchart.

MegaAlgorithm 1 Power Adaptive Step

1: Power of device "α" received from RACH;
2: Set maximum power limit "θ" value based on device class.
3: Provide contention round interval δ.
4: Compute $\delta = \frac{\alpha}{\theta} \times 100$
5: Contention rounds are provided after computed interval δ.
6: **return** δ

The proposed algorithm 1 is affordable by M2M devices that neither have a lot of processing resources nor battery consumption. The maximum power limit can be chosen accordingly through Table 2 based on the device application domain. The chosen value is termed as θ. Through algorithm 1, the contention round interval δ can be calculated. The current standard duration of single time slot is usually 1 sec. The length of contention window can be calculated as equation 14. The proposed algorithm simplifies the complication of longer wait time in following short steps illustrated in the flowchart. The flowchart of the algorithm is shown in Fig. 6.

$$CW = slot_{time} \times \delta \tag{14}$$

B. COMPLEXITY ANALYSIS

Particularly algorithm complexity is related to how fast or slow an algorithm can perform. If we consider input size to be "n" and having time function T_n for defining the time taken by an algorithm. By this definition the complexity of the proposed algorithm is linear or O(n). Informally it is meant that the algorithm complexity running time will increase linearly according to the size of the input. Complexity is not only defined through time function but it can be defined through implementation complexity. The execution of algorithm also depends on processor speed, compiler, disk speed and for all calculation require a lot of power consumption. Similarly, like time complexity, space complexity is also necessary to compute that quantifies the amount of memory or space taken by an algorithm to execute as a function depending on the length of the input. Since in the proposed algorithm, the input depends on the number of devices and the algorithm does not suggests for keeping buffers for handling retransmission messages. Therefore the space complexity of the proposed algorithm is $\Theta(1)$, here additional space used is only the constant number of indices. If buffering is adjusted in the algorithm then the space complexity becomes $\Theta(n + 1)$. Where n is the number of messages which are in waiting state.

C. USE CASES

1) DIFFERENT POWERS

More specifically, in first use case, if the device had a transmission in the first slot then the access probability may reduce for next slot transmission if the other device power remains same. The access probability may increase if other device transmission power is different than previous device attempting for second access slot. In lame terms the access probability depends upon the generated ratio δ in algorithm 1.

2) SAME POWERS

In the second use case, if the devices has the same power, in this case the algorithm is acts as normal Random Slotted Aloha. Each device may have same access probability. The results of the simulation are discussed in Section VI.

D. OPTIMIZATION STEP

The second phase of the paper proposes an optimized technique. The optimized step is deployed further on eNB node. The data received at eNB node is provided spectrum based

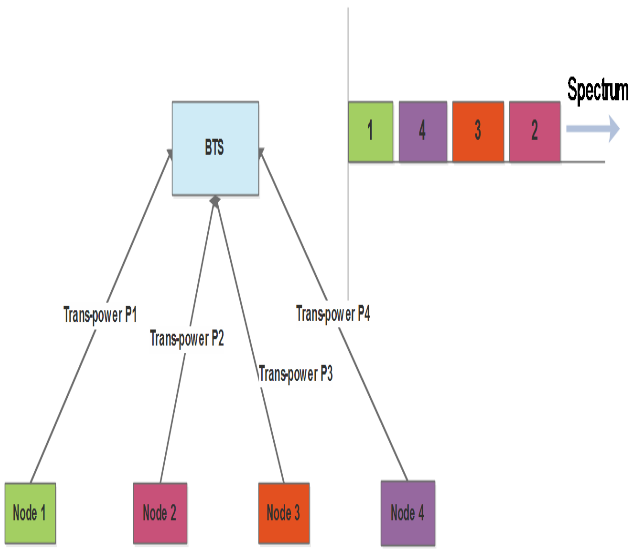

FIGURE 7. Phase 2.

Optimized Step 2 Optimization Hypothesis

Power of device γ received at eNB node;
2: Case 1: $\gamma(m) < \gamma(m-1)$;
Case 2: $\gamma(m) > \gamma(m-1)$;
4: Case 3: $\gamma(m) == \gamma(m-1)$;
For case 3, access probability depends on message size.
6: Compare with other requesting devices;
Select lowest power device;
8: Send data on spectrum of selected device;

on the transmission power that each device may afford. After receiving request from devices, the eNB send a uplink grant to selected device. The selection is based on Table 2. Since the channel interferences and pathloses may create the computation complex therefore the optimized step can be solved theoretically. Fig. 7 elaborates the process. The algorithm of proposed hypothesis is as following. The complexity of this optimization phase is O(1), since it performs comparison at base station or eNB node in case of 5G networks. This is a dynamic step and decisions is made at the instantaneous time frame. The devices does not require to wait and comparison is made on available devices having data.

E. ESTIMATION OF PREAMBLE PROBABILITY

After data transmitted by the devices, it can be assumed that the eNB computes collision, idle and successful preambles. Suppose t can be considered as time of transmission of preambles, which can be written as following equation 15.

$$C_s(t) + C_I(t) + C_c(t) = F \tag{15}$$

Here F are the total number of preambles, $C_s(t)$ are the number of successful transmitted preambles, $C_I(t)$ are the idle preambles and $C_c(t)$ are the collision occurred preambles. Further dividing by F, we can get the probabilities, as shown in 16 equation.

$$\frac{C_s(t)}{F} + \frac{C_I(t)}{F} + \frac{C_c(t)}{F} = P_s(t) + P_I(t) + P_c(t) = 1 \tag{16}$$

Here $P_s(t)$, $P_I(t)$ and $P_c(t)$ are probabilities of successful, idle and collision preambles respectively. For further calculating probability of each segment, following equation is shown.

$$P_c(t) = \left(1 - \frac{1}{F}\right)^{A(t)} \approx e^{-\frac{A(t)}{F}} \tag{17}$$

where $A(t)$ is the number of arrivals in time t. And it can be estimated from following equation 18.

$$A(t) = Fln\left(\frac{1}{P_c(t)}\right) \tag{18}$$

From above equation it is clear that any small changes in $P_c(t)$ will be accompanied with large changes in estimated number of device's $A(t)$.

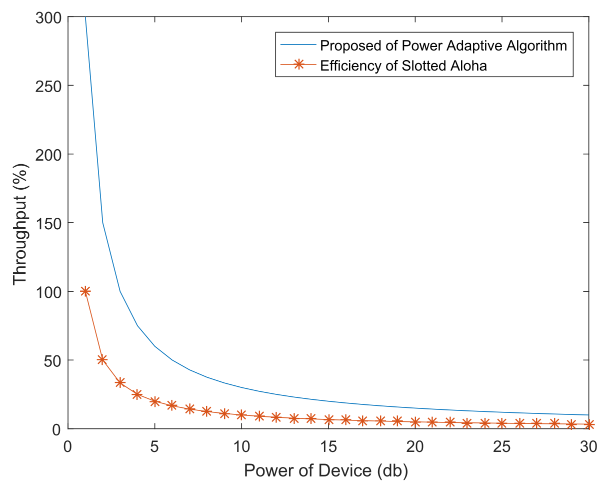

FIGURE 8. Performance comparison.

IV. SIMULATION AND RESULTS

In this section the original Slotted Aloha is compared with proposed power adaptive Slotted Aloha algorithm in terms of energy efficiency and throughput. The simulation is coded on Matlab. The results were achieved after realization through 100 M2M devices having contention round $R = [25, 40, 70]$. Through the simulation it is shown that the throughput of traditional Slotted Aloha remain same while efficiently implying the power consumption. For throughput considering the average termed as Φ. Fig. 8 shows that a priority is given to low powered devices after adjusting the contention round interval. With power limit set to 20db, the proposed algorithm can transmit 300 packets in short interval of time, this cause the low powered devices to send data without waiting for longer period of time, in later version of Slotted Aloha devices have to pass a fixed period of time after which they could transmit. The parameters used in simulation are shown in Table 3. In order to evaluate the packet arrivals Fig. 8 shows ratio of generated packets those are transmitted successfully.

TABLE 3. Simulation parameters.

Parameters	Value
No of Device	100
Packet length	128
Bit rate	512e3
Symbol rate	256e3
Propagation Delay	0.01
Propagation Loss	3
Standard Deviation	6
Service Radius	100 m
Capture Ratio	10 db
Carrier/Noise Ratio	30

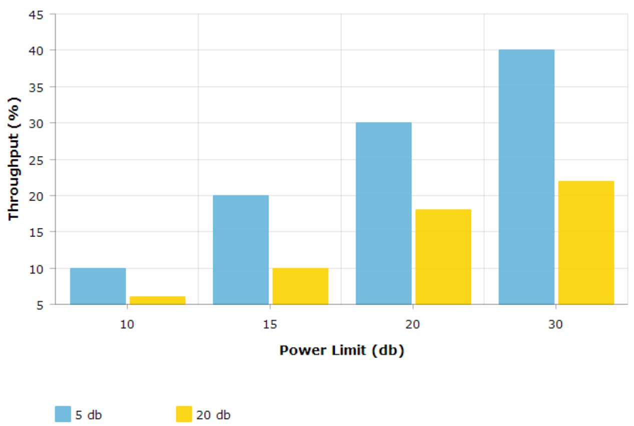

FIGURE 9. Transmission graph.

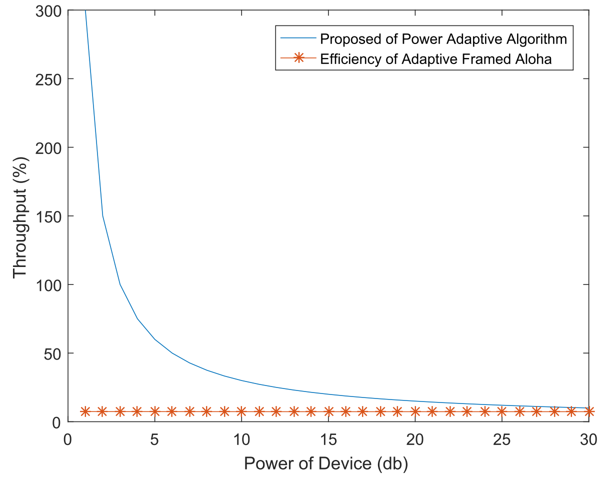

FIGURE 10. Performance comparison.

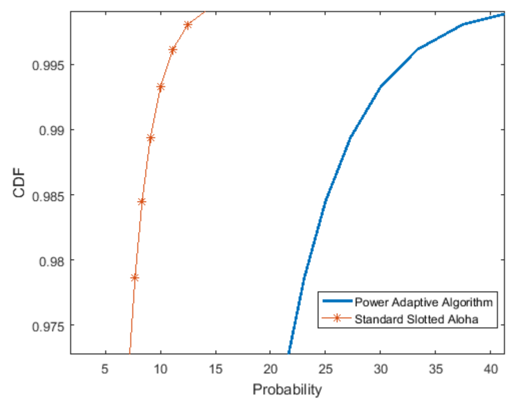

FIGURE 11. CDF of proposed algorithm.

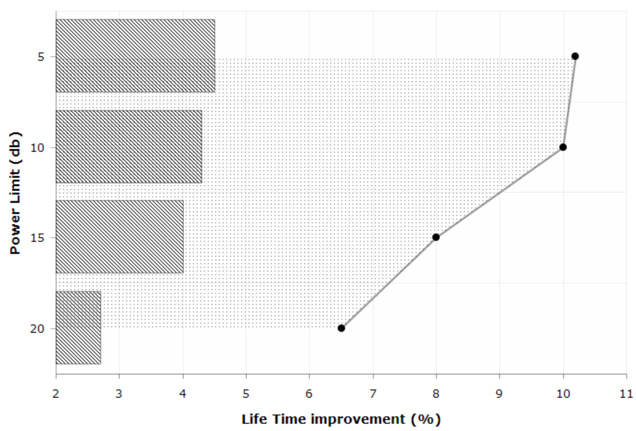

FIGURE 12. Life time improvement of devices.

Successful transmission of messages ratio is increased specifically for low powered device. Fig. 9 shows a comparison of results for devices having 5 db and 20 db powers. A priority is given to low power device and thereby achieve a better transmission rate as compared to device having high power. When the power limit if set to 10, 5 db devices attain 20 % of throughput whereas high powered device having 20 db achieve only 6% of throughput. Similarly while setting different power limits such as 15, 20 and for 30 dbs the average throughput for 5db device equals to 26%. For further solving the problem the optimization step is theoretically calculated at the BS/enhanced NarrowBand (eNB) level.

Fig.10 illustrates a comparison between adaptive frame Aloha technique [19] with proposed power adaptive Slotted Aloha technique. Clearly a better energy efficiency is achieved while keeping throughput steady by proposed technique for low power devices. Adaptive frame Aloha restricts the transmission of the devices thereby reducing the throughput, in contrast to the proposed power adaptive Slotted Aloha technique it gives priority to low power devices usually used in health care and require immediate resource for the transmission and without affording to wait due to restriction on power consumption. Furthermore Fig. 11 illustrates the cumulative distribution function of the proposed algorithm verses the standard Slotted Aloha technique. The proposed algorithm probability of transmission is 50% more as compared to standard protocol without the addition of complexity of implementation and cost of delay during transmission. Traditionally wait probability was to be calculated that was an essential part during a successful transmission. There is a significant increase of battery lifetime while having throughput more than 60%. Talking about lifetime, Fig. 12 illustrates

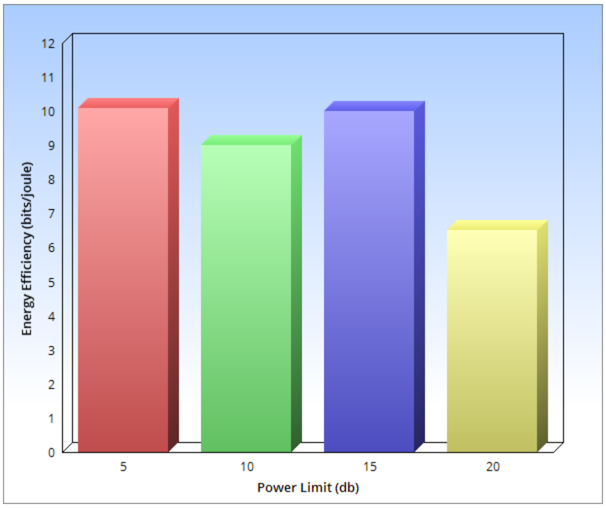

FIGURE 13. Energy efficiency graph of devices.

the increased lifetime of device to 45%, since the proposed algorithm targets low powered devices therefore it can be seen that the efficiency works for low powered devices like 5 db reaches to 4.7% increased lifetime, whereas device having 20 db power gains life time of only 2.8%. Device having 10 db power gains 4.5% increased lifetime and 15 db powered device gain 4% life time. Fig. 13 similarly shows gained energy efficiency having units of bits/joule. Device having 5 db power achieves 10% of energy efficiency where as 20 db device achieves 6.5% of energy efficiency. A fluctuation can also be seen at 10 db powered device reaching 9% of gained energy efficiency.

V. CONCLUSION

In this work, the research is focused on improving the energy efficiency of Random Slotted Aloha for uplink communication. To this end, the paper first proposed a power adaptive scheme where the access probability of the devices are adjusted with random contention round intervals according to device power to achieve better energy efficiency. To satisfy the current difficulty of low powered devices data transmission, the paper proposed power adaptive approach. Simulation is performed for the analysis of the average throughput for this scheme, the results also shows better achieved energy efficiency. The adjustments in the contention round intervals depends on the threshold set for the device as well as of device power. Access probability was also calculated along with transitions states. Due to the necessity of spectrum the paper progressed towards second optimized phase. The optimization phase algorithm further propose a hypothesis at base station level for processing the low powered devices on spectrum. The optimization algorithm have complex unknown environments conditions such as channel propagation and pathloses for this reason in the paper proposed it algorithmically. An improvement in life time and energy efficiency was achieved with an increase in life time to 5% and the energy efficiency at 10% rate, while keeping the reducing the time and space complexity and throughput steady. For future research direction, our research will focus on addressing the effect of dynamic device power classes and change in the number of devices on our adaptive schemes and try to propose a framework to address this challenge accordingly.

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ANUM ALI received the bachelor's degree from the Sir Syed University of Engineering and Technology, Pakistan, in 2005, and the M.Sc. degree from the University of Lancaster, U.K., in 2007. She is currently pursuing the Ph.D. degree from the University of Engineering and Technology, Lahore. She has experience of seven years in research and development. She is a Research Officer with the IoT Systems Laboratory, University of Engineering and Technology, Lahore, Pakistan. Her research interests include space and satellite communication modules and wireless sensors communication including M2M.

GHALIB A. SHAH received the B.Sc. degree in mathematics and the M.Sc. degree in computer science from Bahauddin Zakariya University Multan, Pakistan, in 1997 and 2000, respectively, and the Ph.D. degree in computer engineering from Middle East Technical University, Ankara, Turkey, in 2007. He joined the College of Electrical & Mechanical Engineering, National University of Sciences and Technology, Islamabad, as an Assistant Professor. He was with the Next Generation Wireless Networks Laboratory, Koc University, Istanbul, as a Research fellow, from 2011 to 2012. He is currently a Professor with the Sultan Quboos IT Chair, University of Engineering and Technology, Lahore.

MUHAMMAD SHOAIB, photograph and biography not available at the time of publication.