Energy Efficient MAC for Cellular-based M2M communications

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1. Abstract

The high demand for energy efficient MAC protocols is no news. Therefore, it is important to design new MAC protocols or modify existing models to meet the present and future standards. This paper briefly introduces an overview existing MAC protocols for M2M communication and observes energy efficient MAC protocols over cellular-based networks. It goes further to discuss the current problems of existing MAC protocols, factors affecting their performance rates and propose a logistic approach to a sustainable solution. Three techniques were considered, taking advantage of node distinctions, traffic pattern, time slot allocations, cluster node size and so on.

Index Terms – Media Access Control (MAC) protocols, M2M Communications, Cellular-based networks.

2. Introduction

The fast-paced growing world of technology is experiencing a magnificent turn around in data transmission, communication between devices, sharing and consumption of data, security of data and a host of other numerous impacts. These devices play significant parts and concepts of our everyday lives, ranging from businesses (large or small scale), social, health care, e-commerce, agriculture, life science etc. These smart devices are of small scale, dealing with simple data transmission processes and on large scale platforms, dealing with extensive and complex transmission of data. One of the huge feats of large scale applications is the Machine-to-Machine (M2M) communication also known as Machine-Type Communication (MTC) and it constitute the basic communication paradigm in the emerging Internet-of-Things (IoT). It is defined as the ability of machines to communicate with reduced or without human intervention. It is one of the newly developed communication technologies with fast growing in recent years, which can be widely applied in many areas [1]. The main elements involved are sensors, a wireless network and a computer connected to the Internet. In general M2M communications refers to cellular communication for embedded systems and are very similar to LAN or WAN networks. A few examples of cellular networks are GSM-GPRS, CDMA, MOBITEX, EDGE etc.

Largely, most applications based on M2M communications usually involve the network of a large number of devices and a basic issue is efficiency management of the network resources.

The Medium access control (MAC) is a sub-layer of the data-link layer, concerned with sharing communication which is common amongst networked systems. M2M communication has failed to produce scalable MAC protocols which are able to grant access to large-scale concurrent channel in an M2M network. Since existing cellular networks are built and used for small number of long-lived HoC session, such that it is unable to survive when it is met with massive M2M communications. This leads to network congestion, radio network congestion, signaling network congestion and so on. Also, there exists issues regarding energy efficiency in small data transmission and satisfying QoS. Therefore, there is need to design an efficient MAC protocol for cellular-based M2M communications to curb this prevailing shortcomings. This can be done by improving data aggregation technique.

3. Literature Review

The issue in M2M networks is as old as man; therefore energy efficient MAC protocols were created to mitigate these problems. MAC protocols for M2M communications should be efficient, scalable, consume low power, have low latency, and be implementable using low cost hardware. Here we will discuss briefly about various categories of energy efficient MAC protocols, their limitations and clustering design for cellular-based networks.

We have two categories of energy efficient MAC protocols; they are Contention-based and Contention-free energy efficient MAC protocols.

3.1 ***Contention-Based Protocol***

This protocol is easy to implement and configure. Here, all nodes equally compete to gain access to the channel in a random manner once they have packets to send and no node is given priority over the other. However, it is expensive and largely unsuited for M2M communications due to collision.

A. *Sensor-MAC:* it utilizes sleep and listening time. The idea is to decrease the listening time by putting nodes to sleep periodically and listen when they are awake. The timer is set during the sleep and it is responsible to awake the nodes when its time. Here, every node optionally chooses its sleep time. It solves idle listening problem.

B. *Wise MAC:* it utilizes CSMA by using permeable sampling technique to reduce energy wasted during idle listening. Each node has its sleep schedule and keeps track of others' schedules as well. When a node has a packet to send, it uses the knowledge of its neighbour's schedule to send preamble such that the receiver wakes up right in the middle of the preamble. This scheme cause a drastic reduction in energy wasted due to overhearing.

C. DSMAC: Dynamic Sensor MAC fundamentally operates like S-MAC. It implements an additional dynamic feature to S-MAC. It uses flag value to check active or sleep intervals. When the flag value is 0, the frame size is doubled and when it is 1, the node is synchronized with its neighbours and SYNC packets are already sent. The latency performance here is better than S-MAC

3.2 ***Contention-Free Protocol***

This protocol is concerned with scheduling timeslots and assigns resource for each node. Here, there is no collision, idle listening and overhearing are avoided since nodes are only active during their timeslots and go to sleep when it not theirs. This requires strict time synchronization due to extremely short timeslots.

*A. TRAMA (*Traffic Adaptive MAC*):* Here, time is divided into two: the reservation period and the transmission period. In the reservation period, nodes compete to gain access to the channel with a map that contains the priorities of each node. In the transmission period, only transmission of packet in different time slots is allowed so that channel is accessed in a TDMA manner and free of collision. TRAMA reduces power consumption effectively by allocating time slots only to the nodes that have packets to be sent and puts all other nodes in sleep mode.

B. ER-MAC: This protocol allows nodes to go to sleep to reduce energy consumption. It allocates timeslots according to their circularity which is considered to be unfair. The circularity is based on relative energy and flow rate.

C. D-MAC: In this protocol, data are gathered from source to sink in a data gathering tree. Here, timeslots are allocated depending on the data gathering tree. It achieves low delay but avoids collision mechanism.

Traditional MAC protocols include Static TDMA (Static Time Division Multiple Access), Dynamic TDMA and CSMA (Carrier Sense Multiple Access).

3.4 MAC Design for M2M Communications

The typical way for machine nodes to access the BS is through Random Access Channel (RACH) of the LTE-Advanced. When a packet is generated at a machine node, it tries to gain access to the base station directly and since the nodes uses batteries; it requires a long battery life. If a contention-free protocol is used, there will be massive waste in energy as the device tries to send data directly to the BS. On the other hand, if a contention-based protocol is used, network congestion, including radio network and signaling congestion will mostly likely occur, when large number of device try to connect to the BS. Energy will be wasted due to data collision and idle listening.

4. PROPOSAL

Similar to Wireless networks, the introduction of Data Aggregation is beneficial to M2M communications over cellular networks. Also to tackle the issue of energy efficiency regarding accessing massive data in cellular networks, three concepts have been introduced. They are Partial clustering, Frame formation and Medium Access Design (Idle Listening Reduction in CSMA).

4.1 *Partial Clustering*

Clustering is has been widely used over large number of wireless networks. In partial clustering, nodes are grouped in distinct clusters where one is selected as the cluster head (CH). Before now, cluster members (CM) communicate directly to the BS but in this case, cluster members communicate with the CH which then passes the messages from the cluster members to the BS. To save energy, only nodes far from the BS should be grouped in clusters. This concept performs better than full clustering and non-clustering, saving energy from data transmission. In cases where cluster size is too small, the traffic load within clusters will be too light to cause idle listening and collision.

4.2 *Frame Formation*

Here, the frame is divided into two parts for communication to the BS. The first part handles communication from the cluster members to the CH (Cluster Head) while the other part basically handles communication from the CH to the BS. Here, contention-based protocols are implemented since they perform better than other MAC protocols in terms of time efficiency. In order to avoid the problem of idle listening and collision in the clustering concept, CSMA is deployed for intra-cluster communications. In the second part of the frame, since the CHs has different amount of data for transmission, according to the cluster size, we deploy reservation based protocol to tackle different patterns of traffic in the CH and improving energy efficiency in communications. This concept is applicable and interoperable with existing cellular networks.

4.3 *Medium Access Design/ Idle Listening Reduction in CSMA*

Since idle listening and collision is major issues in intra-cluster communication, we can reduce them by splitting the first part of the frame into multiple phases. In every phase, each cluster independently transmits their packets using the CSMA protocol. This scheme reduces the idle listening problem to an extent by allocating sleep time to some designated nodes instead of listening. However, sleep power becomes lesser than listening power, hence, a reduction in energy wastage. But this scheme largely downplays the fairness of each individual node. Below is a workflow of the proposed Medium Access Design Scheme.

- Determine Th and Sm for Clustering
- If cluster Tp > Th $\rightarrow$ CM
- Pick a cluster with low Tp as CH
- If $C_s < S_m$, do not consider for CM

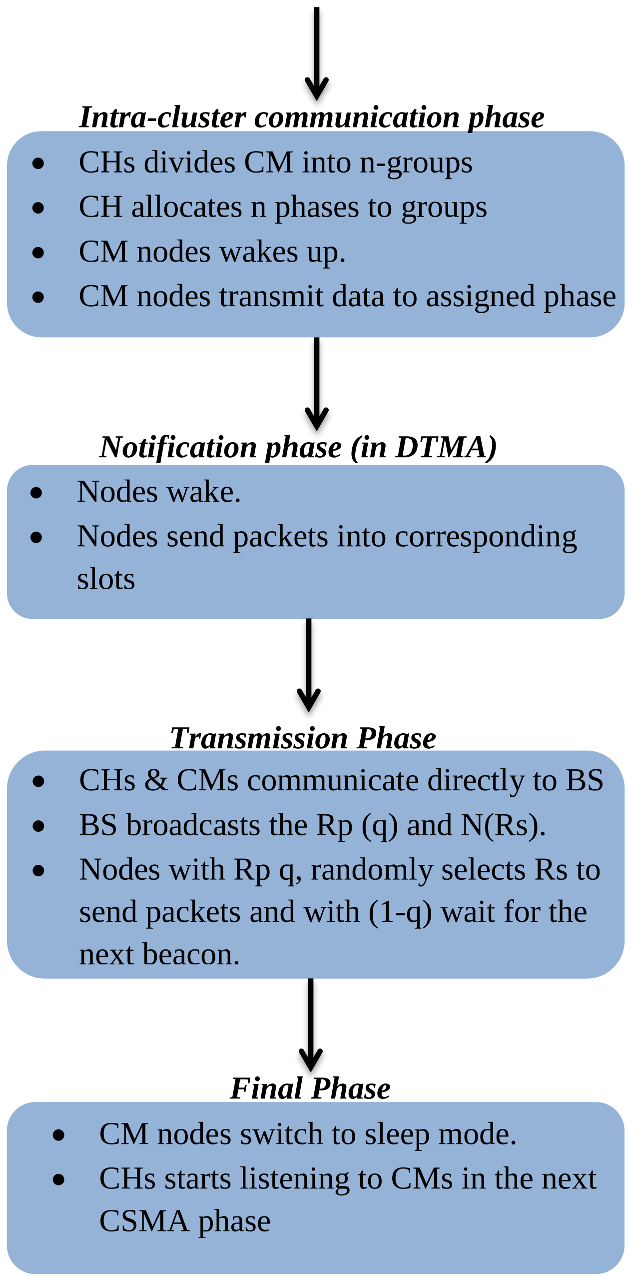

Fig 1. Workflow of Idle Listening Reduction in CSMA

Where:

Th = Threshold,
S_m *= Minimum Cluster size,*
Tp = Transmission Power,
Cs = Cluster size,
Rp = Reservation probability,
N(Rs) = Number of reservation slot.

5. CONCLUSION

It is required for an energy efficient MAC protocol over cellular-based network to be collision-free and have minimal idle listening. Owing to the high demand of cellular networks, addressing these problems is of great importance. In this paper we have been able to implement different techniques to mitigate these shortcomings. However, the efficient implementation of these techniques largely depends on the communication of nodes with the bus station, distance between nodes and the base station and proper allocation of sleep and listen time slots. The proposed techniques (Partial clustering, Frame formation and Medium Access Design) should be an efficient solution for most cellular networks if well implemented.

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