# Proximity Coordinated Random Access (PCRA) for M2M Applications in LTE-A

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***Abstract*—A significant amount of research has been conducted on adapting 3GPP Long Term Evolution (LTE) and LTE-Advanced (LTE-A) random access to be more efficient for machine-to-machine (M2M) devices because of the huge number of such devices that may reside in each LTE/LTE-A cell. However, there are other attributes of M2M applications that can be used as the basis of independent efficiency improvements. One characteristic which has been overlooked thus far is the spatial and temporal correlations that often exist in the activity of neighboring M2M devices belonging to the same M2M application. In this paper, we illustrate how these correlations can be exploited by coordinating the preambles to be used by neighboring M2M devices to reduce the number of collisions during LTE-A random access, particularly in wireless sensor network (WSN) type applications. The technique is referred to as proximity coordinated random access (PCRA). Through simulation of an example local preamble coordination algorithm that can be executed autonomously by randomly deployed devices of the same M2M application, we demonstrate an increase in the efficiency of the random access process.**

***Keywords—LTE-A, Random Access, M2M, WSN***

## I. INTRODUCTION

There has been considerable interest in deploying machine-to-machine (M2M) applications for the utility, healthcare, automotive and other vertical markets in parallel with existing human-to-human (H2H) services over Long Term Evolution Advanced (LTE-A) wide area wireless networks. One of the challenges in this pursuit is the potentially huge number of M2M devices that may reside in each LTE-A cell and the effect in particular on the random access channel efficiency due to overload. Various mitigations have been proposed in the literature such as extended access barring (EAB), separation of random access resources between M2M and H2H applications and slotted random access for M2M devices [1-4].

Independently of the huge number of devices and overload concerns, there are other aspects of M2M which can be exploited to improve the efficiency of the random access process. One characteristic which has been overlooked thus far is the spatial and temporal correlations that often exist in the activity of neighbouring M2M devices belonging to the same M2M application (note that [5] addresses spatial partitioning of a cell but does not exploit correlations in traffic patterns). A simple example is a wireless sensor network (WSN) which reports the progress of some travelling disturbance (e.g. fire, flood, air pressure etc.) across a wide geographical area and this is the model that will be employed in the remainder of this paper. We will assume the sensor devices are geographically fixed, are normally resident in the low energy RRC_IDLE state of LTE-A and report on an event basis when the travelling disturbance reaches them. In standard LTE-A, the devices must independently contend for access once the disturbance has arrived by randomly selecting a preamble and sending it during the next periodic random access slot. Because there is no coordination in the choice of the preamble between devices in proximity of each other, collisions can occur if two devices select the same preamble by chance. This is illustrated in Fig. 1a below. The situation is exacerbated by the fact that the devices must wait for a periodic random access slot to send their preambles, so there is some build-up of pending random access requests in the system as the disturbance propagates.

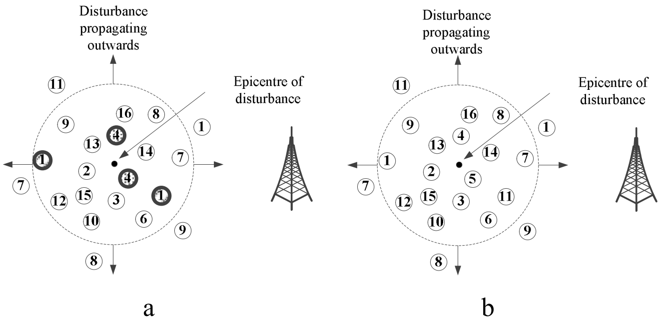

**Fig. 1** Random access caused by WSN M2M application

a Standard LTE-A: random preambles with 2 collisions

b PCRA: fixed coordinated assignment of preambles

An improvement using a technique known as proximity coordinated random access (PCRA) is shown in Fig. 1b. Rather than devices independently randomly selecting a preamble on demand when they have data to send, the preambles are coordinated ahead of time in a fixed manner according to the spatial characteristics of the WSN. In particular, devices which are in proximity of each other are assigned different preambles. This guarantees that wherever the disturbance originates, at least the first set of devices to detect the disturbance will send random access requests with distinct preambles which will therefore be collision free unless the disturbance moves very quickly or other devices in the cell which are not part of the WSN need to send random access requests and select the same preamble. This is extremely important because it is crucial to minimize uplink latency when the disturbance first occurs.

If the devices are installed at specific planned locations, the preamble coordination and provisioning can occur prior to or during deployment. A more complex scenario is when the devices are spread randomly (e.g. by dispersing them from a vehicle), in which case a protocol/algorithm is required for the devices to discover their neighbours and coordinate preambles dynamically. An example algorithm is discussed in the next section.

It is important to note that a sensor device only needs to use its assigned fixed preamble when an event occurs which is likely to also affect its neighbour devices. For regular functions such as location update and sending of RRC measurement reports, the device can use a randomly generated preamble per standard LTE-A. The benefit of PCRA is that it reduces the number of collisions between devices associated with the same M2M application which send data in a spatially and temporally correlated manner; although it does not directly reduce collisions between devices associated with different M2M applications or between M2M and H2H devices, there is an indirect global benefit due to the lower number of retransmissions in the whole system. The assignment of preambles in PCRA is deterministic, however all available preambles should be used in an equitable manner (i.e. with almost equal frequency) to maximize the benefit of the scheme. When collisions do occur with PCRA, the respective devices can fall back to using a randomly generated preamble for retransmissions to prevent a collision deadlock.

## II. PREAMBLE COORDINATION ALGORITHM

In a planned WSN deployment in which the locations of devices are known within an LTE-A cell at deployment time, it is possible to execute an offline equitable graph colouring algorithm (e.g. [6]) to assign the *m* available preambles to devices such that they are each employed with almost equal frequency and neighbouring devices are assigned distinct preambles. The devices can then be provisioned statically with their assigned preambles during deployment or dynamically over the LTE-A air interface post deployment.

However, such a global view of the device topology is not always available in a WSN because devices can be deployed in a random fashion. In this scenario, the devices must learn about the presence of their neighbours dynamically and coordinate the assignment of preambles between themselves in a distributed manner. There are different ways of approaching this objective which affect the overall quality of the preamble assignment and involve different convergence times and energy consumption on the part of devices. This paper does not address these different approaches; rather it presents one example preamble coordination algorithm and shows how it can yield a more efficient random access scheme compared to the existing random assignment of LTE-A preambles. Furthermore, the algorithm is specified at a high level and we do not address the communication medium which devices use to perform the coordination; it could for example be via a personal area network such as IEEE 802.15.4 or LTE Direct.

The example preamble coordination algorithm is illustrated via pseudo code in the Alg. 1 box. Each device first undertakes a random experiment to see whether it will act in the role of a preamble server or client. Clients request a preamble from a server when they become aware of a server in their proximity.

A preamble server first tests whether it can hear the broadcasts of other preamble servers; if it can, it relinquishes its server role because this is an indication that servers are located too closely together. Servers which pass the distance test randomly select one of the *m* available preambles for themselves, leaving *m-1* preambles to be assigned to neighbouring clients. They then begin broadcasting their role as servers initially at a low transmit power, but ramp up their transmit power in a stepwise fashion up to some maximum limit. This ramping allows the nearest preamble clients to become aware of a preamble server and request a preamble assignment before more distant clients. This is important because a server can only make a maximum of *m-1* assignments to clients before its preamble supply is exhausted, and these assignments should ideally be to the nearest *m-1* clients in order to optimize the spatial reuse of preambles. Preamble servers maintain a record of which of the *m* preambles they have assigned; when a client requests a preamble, a server randomly chooses between the remaining available preambles to assign to the client. This random assignment of reaming preambles is important because a server may not assign its full set of *m* preambles and there should be no bias as to which preambles remain unassigned.

```
// TRIGGER_PROBABILITY, M, MAX_COUNT_1,
// DELTA_TIME_1, MAX_COUNT_2 and DELTA_TIME_2
// are algorithm parameters

while (finish != true) {
    rand = selectRandomNumber(uniform, 0,1);
    if (rand < TRIGGER_PROBABILITY) {
        functionAsPreambleServer(M);
    }
    else {
        functionAsPreambleClient ();
    }
}

functionAsPreambleServer (integer nPreambles) {
    if (serverCannotHearOtherServers) {
        selectPreambleRandomlyForSelf(uniform, nPreambles);
        for (count = 0; count < MAX_COUNT_1; count++) {
            rampUpTransmitPower(count);
            setTimer (DELTA_TIME_1);
            while (timerHasNotExpired()) {
                respondToPreambleRequestsFromClients();
            }
        }
        finish = true;
    }
}

functionAsPreambleClient () {
    for (count = 0; count < MAX_COUNT_2; count++) {
        wait (DELTA_TIME_2);
        if (deviceCanHearPreambleServers()) {
            server = selectNearestPreambleServer();
            assignedPreamble = requestPreamble(server);
            finish = true;
        }
    }
}
```

Preamble clients periodically listen for preamble server broadcasts. When a client detects one or more servers, it requests a preamble from the nearest such server based upon a minimum path loss criterion (path loss = transmit power listed in broadcast – received power). If the nearest detected server has no remaining preambles, the client requests a preamble from a different server if and when it is detected. It is possible that a client is not in the proximity of any server with remaining preambles and so will never be assigned a preamble. To allow for this, if a client does not detect a server within a certain time, it repeats the initial random experiment and possibly becomes a preamble server.

## III. PERFORMANCE ANALYSIS

In this section, we provide the results from a simulation of PCRA using the example preamble coordination algorithm specified in the previous section. The simulation employed an LTE-A cell of radius 200m in which 20000 WSN devices were distributed randomly. Preambles servers initially broadcast with 5m range and stepped up their transmission power until the range was 15m. After preamble coordination was complete, a disturbance originated at a random cell location and propagated omnidirectionally at a specified speed. We employed $m$=54 preambles as suggested in [3] and TRIGGER_PROBABILITY = $1/m$. The simulation was repeated for 100 random layouts of devices (each resulting in a separate execution of the preamble coordination algorithm) and for each layout, 100 random locations of the disturbance epicentre. We considered the worst case scenario in which the disturbance occurred with a full random access slot period remaining to the next random access slot.

Fig. 2 compares the proportion of unique preambles for PCRA and standard LTE-A random access as the disturbance propagates at 1000m/s for 5ms and 10ms random access slot periods. The proportion of unique preambles is higher for a 5ms random access slot period at an arbitrary time because random access opportunities are more frequent and there are expected to be fewer devices sending preambles at each opportunity.

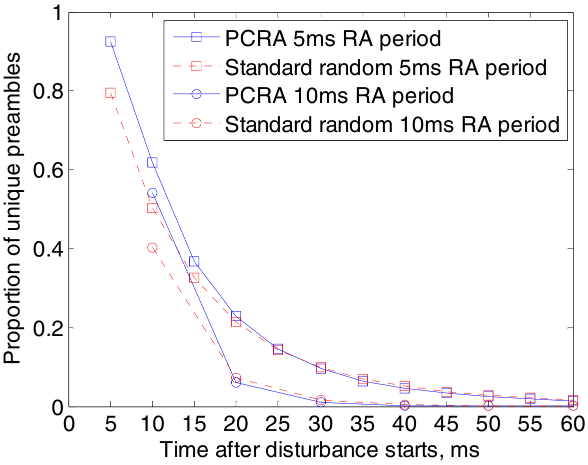

**Fig. 2** *Proportion of unique preambles for different random access slot periods and a disturbance speed of 1000m/s*

When the disturbance first originates, there are relatively few devices contending for access so the proportion of unique preambles is relatively high. As the disturbance propagates, the number of devices with pending requests increases with the perimeter of the disturbance front and so the proportion of unique preambles decreases. PCRA can be seen to exhibit a performance gain relative to standard LTE-A random access which is particularly pronounced in the first random access slot period after the disturbance originates (e.g. the proportion of unique preambles is 0.54 for PCRA versus 0.40 for standard random with a 10ms random access slot period). As discussed previously, this is crucial from an application perspective because it minimizes uplink latency when the disturbance first occurs.

## IV. CONCLUSION

In this paper, we introduced the concept of proximity coordinated random access (PCRA) to improve the efficiency of the LTE-A random access process for M2M applications such as a WSN in which the devices exhibit spatial and temporal correlation in their activity. A sample preamble coordination algorithm was specified for randomly distributed devices, and a simulation of the algorithm illustrated the efficiency gains versus random preamble assignment. Future work will focus on advanced preamble coordination algorithms which increase the efficiency of the LTE-A random access process further and reduce the convergence time of PCRA. The application of the PCRA concept to 5G networks is also a high priority.

## ACKNOWLEDGMENT

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