Radio Resource Management for M2M Cellular Communication

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INTRODUCTION

- With M2M communications, devices talk to each other through wired or wireless connections and share data without direct human intervention.
- The use of M2M communications is particularly well suited to interact with large number of remote devices acting as the interface with end customers, utilities etc.
- In this way devices such as smart meters, signboards, cameras ,remote sensors, laptops and appliances can be interconnected to support a variety of new applications.

INTRODUCTION

- With an architecture in place, numerous challenges remain for radio resource management(RRM) for M2M communications in cellular networks.
- For example time and frequency resources are to be shared between Human-to-Human(H2H) users and Machine-Type Communication devices(MTCDs),thus resulting in co-channel interference among them which plays a role in degrading the performance of cellular networks with M2M communication.

INTRODUCTION

- To the best of the Author's knowledge there has been no work in the literature on radio resource allocation for cellular networks with M2M communications so far.
- The scope of the Authors is hence to examine how H2H user and MTC devices can share available radio resources efficiently so as to mitigate co-channel interference and thus enhance network efficiency.

ARCHITECTURAL ENHANCEMENT TO FULFILL M2M REQUIREMENTS

- The current Radio Allocation Network(RAN) consists of a single node, i.e eNodeB (eNB) that provides the user plane and control plane protocol terminations towards the user equipment (UE).
- In each eNB there exists PHYsical (PHY),Medium Access Control (MAC),Radio Link Control (RLC) and Packet Data control Protocol(PDCP) layers that implement the functionality of user-plane header-compression and encryption.

ARCHITECTURAL ENHANCEMENT TO FULFILL M2M REQUIREMENTS

- The current 3G LTE cellular network is designed only for providing H2H services for user equipments (UEs).
- However with the introduction of M2M communications, the network architecture needs to be improved to accommodate M2M service requirements without sacrificing the qualities of current H2H services.

I.MTCD - RELATED COMMUNICATIONS

- There exists two new network elements in order to enable M2M communications in cellular networks which are MTCD and MTCG (MTC gateway).
- MTCD is a user equipment designed for machine-type communications, which communicates through a cellular network with an MTC server and/or other MTCDs.

I.MTCD - RELATED COMMUNICATIONS

- MTC gateway is required to facilitate communication among great many MTCDs and to provide connection to the backhaul that reaches the internet.
- MTCG will be able to intelligently manage power consumptions of the network, and provide an efficient path for communications between MTCDs.
- Three different M2M communications methods were discussed as follows:

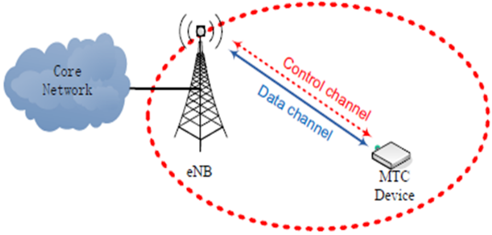
A. Direct transmission between MTCD and eNB:

- Similar to a normal UE, a MTCD has the ability to establish a direct link with its donor eNB.
- Therefore, there exist strong similarities between the eNB-to- UE and eNB-to-MTCD links.
- On the other hand ,MTCDs normally appear in large quantities in the M2M networks and thus exhibit the service feature of group-based communications.

A. Direct transmission between MTCD and eNB:

- Sometimes competitions for radio resources may occur when one or more MTC groups send communication requests to an eNB simultaneously, which may cause network congestion, resulting in performance degradation for both M2M and H2H services.
- Thus intensive measures have to be taken into account to tackle such kinds of problems when a large quantity of MTCDs communicate with the eNB directly.

The figure bellow shows a direct transmission between MTCD and eNB



(a) Direct transmission.

Figure 1

B. Multi-hope transmission with the aid of an MTC gateway:

- MTC gateway can be deployed in cellular networks, where all MTCDs are connected to the eNB indirectly through the relaying of the MTCG so as to mitigate or eliminate negative effects of M2M communications on H2H communications.
- In other words, the end-to-end communication between the eNB may occur via more than one hope, e.g. the eNB-to-MTCG and MTCG-to-MTCD links.

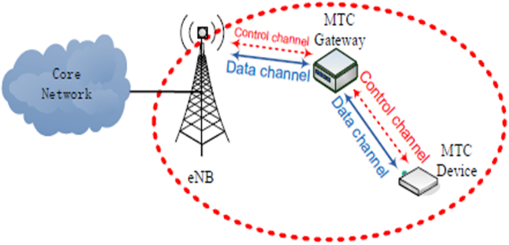
B. Multi-hope transmission with the aid of an MTC gateway

- Besides, MTCDs may establish peer-to-peer communications with each other with the aid of the MTCG or eNB.
- The eNB-to-MTCG wireless link is based on 3G LTE specifications, whereas the MTCG-to-MTCD and MTCD-to-MTCD communications can either be via 3G LTE specifications or other wireless communications protocols such as IEEE 802.15.x.

B. Multi-hope transmission with the aid of an MTC gateway

- The resulting multi-level network management problem can be handled with the aid of the MTCG.
- Each MTCD is controlled by its donor MTCG, which is managed by the eNB. The introduction of the MTCG makes the network topology more complex, leading to challenges as well as opportunities.
- MTCDs are usually grouped for control, management or charging facilities.

The figure bellow shows a multi-hope transmission with the aid of an MTC gateway



(b) Multi-hop transmission.

Figure: 2

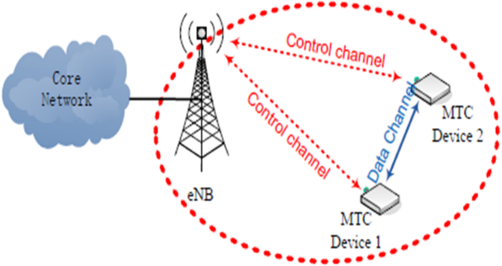
C. Peer-to-peer transmission between MTCDs:

- An MTCD may communicate locally with other entities, which provide the MTCD with raw data for processing and communicating to the MTC server and/or other MTCDs.
- The cellular network can broadcast local services available within a much wider coverage area, thus for automated service discovery, the MTCDs do not have to constantly scan for available local access points as in the case of IEEE 802.11a.

C. Peer-to-peer transmission between MTCDs:

- This is advantageous since leading to significantly reduced power consumption for scanning.
- With the knowledge of encryption keys at both MTCDs involved in peer-to-peer communications, a secure connection can be established without manual pairing of devices or entering encryption keys.
- Moreover, through the control of the eNB via peer-to-peer communications, the interference to other cellular receivers can be limited or mitigated.

The figure bellow shows a peer-to-peer communication between MTCDs



(c) Peer-to-peer transmission.

Figure: 3

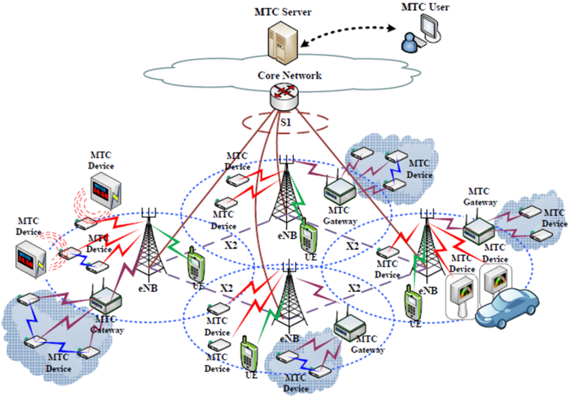
II.ARCHITECTURAL ENHANCEMENT

- In order to support M2M communications, the RAN architecture needs to be enhanced to enable coexisting communications between MTCD-ralated and H2H communications in cellular networks.
- To avoid self-interference and reduce implementation complexity, half-duplex MTCGs are preferred for deployment in the networks.

II.ARCHITECTURAL ENHANCEMENT

- In such fairly manner M2M cellular networks, how to assign and coordinate radio resources to different classes of transmissions become a critical issue.
- Fig. in the next slide gives an example of architectural enhancements to the M2M cellular network.

Fig.Architectural Enhancements to LTE-Advanced Cellular Networks with M2M Communications



RADIO RESOURCE MANAGEMENT FOR M2M COMMUNICATIONS

- There are two major methods for radio resource allocation between M2M and H2H communications which are Orthogonal and Shared resource allocation.
- Allocating M2M and H2H communications in orthogonal channels is a simple solution but leads to low spectral efficiency from a system level perspective.

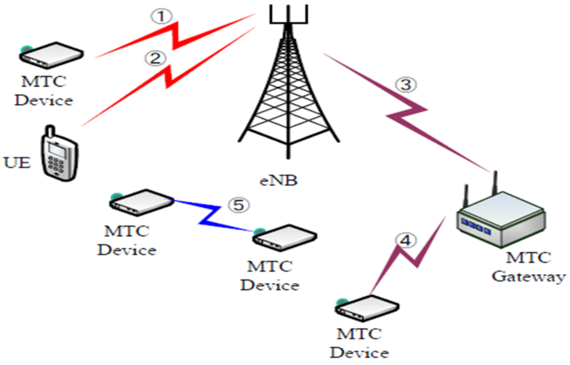
RADIO RESOURCE MANAGEMENT FOR M2M COMMUNICATIONS

- To achieve higher spectral efficiency, M2M communications can reuse the radio resources assigned to H2H communications, resulting in shared channel allocation.
- However, this will cause an increase level of interference in comparison with orthogonal channel allocation.

RADIO RESOURCE MANAGEMENT FOR M2M COMMUNICATIONS

- In mixed H2H and M2M communication networks, there are usually five types of links as illustrated in the figure in the next slide namely: (1) The eNB-to-UE link (2) The eNB-to-MTCD link (3) The eNB-to-MTCG link (4) The MTCG-to-MTCD link (5) The MTCD-to-MTCD link.
- When radio resources are shared among these links, interference becomes a challenging issue.

The figure below shows the transmission links



(a) Transmission links.

Figure: 5

RADIO RESOURCE MANAGEMENT FOR M2M COMMUNICATIONS

- It is critical to exploit the characteristics of links to obtain the well-designed coordination pattern, which can achieve performance gain for almost all users in the network.
- On the assumption of half-duplex MTCGs, every two time slots are grouped together as one basic unit for transmission.
- In the first slot, termed as the backhaul slot, the MTCGs receive signals from the eNB. In the second slot, called the access slot, MTCGs send the data to their serving

RADIO RESOURCE MANAGEMENT FOR M2M COMMUNICATIONS

- The eNB-to-MTCG transmission link has to be reliable to ensure the service quality of the MTCDs associated with the MTCG.
- Thus, the eNB-to-MTCG links are assigned orthogonal parts of radio resources, where as all other links directly associated with the eNB, share the channel.
- In the access slot, all links except for the eNB-to-MTCG links share all the radio resources using various methods.

RADIO RESOURCE MANAGEMENT FOR M2M COMMUNICATIONS

- MTCD-to-MTCD communications are to take place only locally with relatively low power, and using either uplink or downlink channel.
- This implies that these links do not interfere with any other links, where as the inverse of course does not hold true.
- The MTCG-to-MTCG link, however can strictly generate interference with ongoing communication links.

RADIO RESOURCE MANAGEMENT FOR M2M COMMUNICATIONS

- However, since these devices typically serve some spatially very small areas where coverage is typically poor, the impact onto the other links is neglected here.

1. ORTHOGONAL ALLOCATION FOR THE eNB-to-MTCG LINK

- Radio resource allocation and scheduling between the MTCG and MTCDs can be carried out at the MTCG in coordination with its donor eNB.
- Instead of communicating with an eNB directly, the MTCDs associated with a MTCG first establish a link with the MTCG.

1. ORTHOGONAL ALLOCATION FOR THE eNB-to-MTCG LINK

- Via such multi-hop transmission, intense competition against radio resources can be mitigated especially when enormous MTCDs request access to the network resources simultaneously.

1. ORTHOGONAL ALLOCATION FOR THE eNB-to-MTCG LINK

- In addition, the radio resources can also be reused between MTCGs in the case of multiple MTCGs per cell to improve on the spectral efficiency of the network.
- As mentioned before, there is no co-channel interference between the eNB-to-MTCG link and other links due to orthogonal channel allocation in the backhaul slot.

1. ORTHOGONAL ALLOCATION FOR THE eNB-to-MTCG LINK

- For the purpose of achieving high spectral efficiency, resource allocation for the eNB-to-MTCG link needs to be adjusted semi-statically according to service demands from the MTCDs associated with the MTCG.

1. ORTHOGONAL ALLOCATION FOR THE eNB-to-MTCG LINK

- If there are not enough resources available for data transmission between the eNB and MTCG, the associated MTCDs can not be served in time, resulting in QoS degradation.
- Otherwise, when excessive resources are assigned to the eNB-to-MTCG link, the QoS performance of other users such as UEs and other MTCDs may suffer due to insufficient radio resources.

2.Allocation between eNB-to-UE and eNB-to-MTCD Links

- For cellular networks with both H2H and M2M services, the user utility of a service is more informative than the simple QoS indicator due to the diversity of the applications.
- Generally speaking, the user utility of a service is a measurement of its QoS performance based on the provided network services such as the bandwidth, transmission delay and loss ratio.

2.Allocation between eNB-to-UE and eNB-to-MTCD Links

- It describes the satisfaction level of the service delivered to the application.
- With the control of the eNB, radio resources can be efficiently shared between the eNB-to-UE and eNB-to-MTCD links by using the utility-based scheduling scheme.

3.Allocation between MTCD-to-MTCD Links

- In order to improve network efficiency, it is assumed that different MTCD-to-MTCD links share the same radio resources.
- Moreover, MTCD-to-MTCD transmission can share the resources used by the other links owing to the low transmission power of MTCDs.

3.Allocation between MTCD-to-MTCD Links

- In general, the assignment of sub-channels between MTCD-to-MTCD links can be performed through the centralized or distributed way.
- The former can achieve a higher resource efficiency with much more overhead and complexity than the later.

PERFOMANCE EVALUATION

- The performance of cellular networks with M2M communications under the urban scenarios are evaluated through system-level simulations.
- All UEs are evenly distributed in the circular areas around each eNB.
- The MTCD placement is performed as follows: 50 MTCD are located uniformly per sector while 50 pairs of MTCDs are deployed uniformly at random in a floor building, all duty cycled at 10 percent.

PERFOMANCE EVALUATION

- To simulate the realistic scenarios where mixed H2H and M2M services exist in the cellular network, different utility functions are assumed for the UEs and MTCDs.
- When M2M communications are introduced into the network, the performance of existing H2H communications are somehow affected due to the decrease of the available radio resources.
- When the Max-Utility scheduling scheme is applied, such effects can be controlled by adjusting the unified weighting factor of M2M communications, i.e. λ

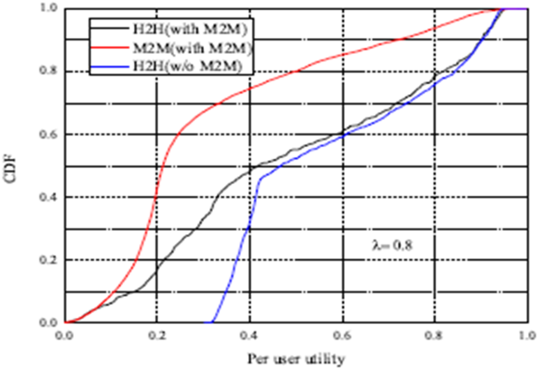
PERFOMANCE EVALUATION

- User utility performances are compared in terms of the given percent point of the cumulative distribution function (CDF) in the networks with different values of λ
- With the increase of the factor value, the performance of M2M communication is improved while the cell edge user performance i.e. the 10 percent CDF H2H performance deteriorates.

PERFOMANCE EVALUATION

- Such improvement in M2M communication and degradation in H2H communication located in the cell center i.e. 50 percent and 90 percent CDF H2H performances, remain virtually unchanged with a variation of λ
- Therefore $\lambda = 0.8$ is used for the network with mixed H2H and M2M services.
- The Fig. below presents the CDF performance of the user utility with and without concurrent M2M communications.

Fig.CDF performance of the user utility with and without concurrent M2M communications



CONCLUSION

- Machine-to-machine (M2M) communications are expected to provide ubiquitous connectivity between machines without the need of human intervention.
- To support such a large number of autonomous devices, the M2M system architecture needs to be extremely power and spectrally efficient.

CONCLUSION

- The required network architectural enhancements with the introduction of various transmission schemes related to MTCDs have been presented.
- Several radio resource allocation schemes for different transmission links have been proposed with the aim of minimizing co-channel interference and maximizing network efficiency.

CONCLUSION

- For future research, practical issues have to be paid more attention to when designing new resource allocation schemes for M2M communications.