
Introduction

In Machine-to-Machine (M2M) communications, thousands of devices wirelessly communicate with each other or with a central controller autonomously without human intervention. The applications include water/gas metering system, aquatic environmental monitoring, healthcare, etc., where M2M traffic is uplink-dominated. Since M2M devices can be deployed in places arduous to access (e.g. the desolate plain or desert), it is promising to power those devices with energy harvesting technology. Energy harvesting technology enables the devices to harvest and convert the ambient energy, such as solar energy, vibration, heat, etc. to usable electricity so as to reach sustainability. In this scenario, it is significant to design appropriate wireless communication protocols to satisfy the requirements and properties of energy-harvesting M2M communications. In our research, we propose two paradigms to evaluate the performance of energy-harvesting M2M in LTE-A cellular system.

Push-Based Scheme

We proposed the push-based uplink scheme for energy-harvesting M2M devices in LTE-A cellular system as shown in Fig. 1. The device should determine whether to enter network entry procedure by checking its energy level. As the number of co-existing devices increases or the number of preambles decreases, the RACH (Random Access Channel) collision probability increases, leading to drastic drop in both the throughput and energy efficiency (i.e., number of successfully transmitted packets per Joule), as shown in Fig. 3(a)(e). Notice that when the number of devices increases, the packet delay in Fig. 3(c) increases to a peak and then drops drastically. The reason is that when the number of devices grows cross the peak value, the throughput almost drops to 0, and thus the packet delay is dominated by only a few packets.
Pull-Based Scheme

We further proposed the pull-based uplink scheme by granting the M2M device scheduled dedicated preamble transmission opportunity as shown in Fig. 2. It is observed that due to periodic scheduling, the packet delay grows linearly as the number of co-existing devices increases as shown in Fig. 3(d), because the schedule period is related to the number of M2M devices in the system. In addition, owing to collision-free scheduling, the achieved throughput is pretty close to the packet arrival rate, 0.2 packet per second, regardless of the number of devices. With the similar reason, energy efficiency does not degrade with the increase in the device number.

Conclusion

In an uplink cellular network with energy-harvesting M2M transmitters, the advantages of the push-based scheme are self-energy-awareness and no schedule signalling cost. But, the push-based scheme may suffer from collision problem and degrades the performance when the number of devices is above an upper bound. The pull-based scheme seems to be an attractive alternative in that it outperforms the push-based scheme in terms of delay, throughput and energy efficiency with the sacrifice of the extra scheduling cost.

![Fig. 2 Pull-Based Scheme](image)

![Fig. 3 Push-based scheme](image)

About the Authors

**Mei-Ju Shin**, Ph.D. Student
Graduate Institute of Communication Engineering, National Taiwan University
Intel-NTU Connected Context Computing Center

**Hung-Yu Wei**, Associate Professor
Department of Electrical Engineering, National Taiwan University
SIGARC PI, Intel-NTU Connected Context Computing Center

Acknowledgments

This work was also supported by Ministry of Science and Technology, National Taiwan University and Intel Corporation under Grants MOST 103-2911-I-002-001 and NTU-ICRP-104R7501.