Cooperative Information Fusion and Inference

Newsletter No. 37 May 2014

Cloud-based machine-to-machine (M2M) communications can be illustrated as Figure 1, requiring networking technology in the cloud, wireless infrastructure, and for machine swarm/ocean consisting of tremendous machines/devices. This research explores effective communication in machine swarm and thus potential architecture for the entire cloud-based machine-to-machine communication scenario.

We first resolved the challenge of massive access from machine swarm to wireless infrastructure (Lien, Chen, Lin, 2011). However, there are 3 key technology challenges (remaining open) to accomplish M2M communication in the machine swarm:

- Spectrum sharing: To support wireless communication of large number of machines, spectrum sharing is definitely required, either for systems with priority (known as cognitive radios) or without priority (known as heterogeneous spectrum sharing networks). We developed detailed characterization of spectrum sharing networking using stochastic geometry, statistical physics, and game theory. From our analysis on connectivity (Ao, Cheng, Chen, 2012) and subsequent networking mechanisms, we may comfortably conclude spectrum sharing to be engineering feasible design.

Ad hoc networking: The scalability of ad hoc networks has been proven to be an open problem (Chen & Lien, 2014). We note such obstacle coming from control signal overhead to establish end-to-end routing table (in the order of N^2). Gossip algorithm was introduced to alleviate communication complexity, to the order of $N\sqrt{N}$, but still away from target level of order N. We have been developing spiral networking using navigation based on physical local sensing, to resolve the challenge of complexity N. As wireless infrastructure may exist in many application scenarios, heterogeneous network architecture was suggested from CIFI to establish a kind of small-world networking to serve as another solution for large machine swarm (Chen, Chiang, Poor, 2013), which may be valuable to support a wide range of applications.

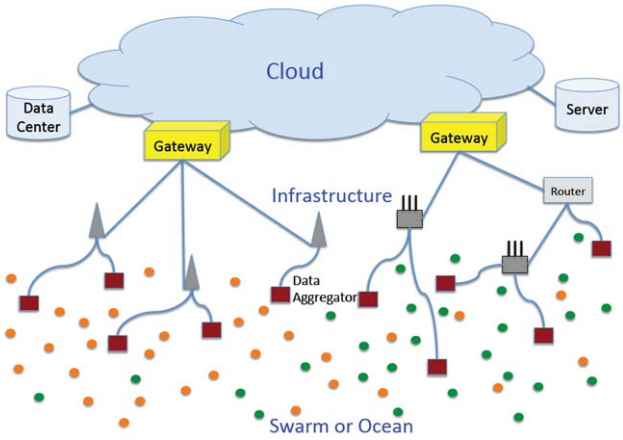

Figure 1: Cloud-based machine-to-machine communications (Chen & Lien, 2014)

- Cooperative networking: Multi-hop (ad hoc) spectrum sharing networking requires cooperative relay, without considering the potential price to pay, interference and energy for relay nodes, as a new kind challenge of network economy (Chen, Chiang, Poor, 2013).

To facilitate engineering spiral networking algorithms for M2M communication in machine swam, we leveraged multi-path transmission in multi-hop networks, we established the effective greedy routing with opportunistic routing for the machine swarm, on top of rough knowledge of spectrum map. By stochastic geometry and network coding, we identified the operating tradeoff for rate-reliability-delay. Furthermore, based on a new cross-layer design in ad hoc networks (from radio resource to PHY), radio resource management for QoS guarantees under the heterogeneous network architecture, which can be designed for general cyber-physical systems (Lien, Cheng, Shih, Chen, 2012). The challenging error control can be amazingly realized through an innovative path-time codes without the need of feedback information nor control, also perfectly for open-loop communication in cellular (Lai, Lee, Chen, Biglieri, 2014). Together with distributed source coding leveraging the broadcast nature of wireless communications, network coding, and greedy routing, we demonstrated that in-network computation in cognitive sensor network significantly achieves 10 dB gain in network throughput per bandwidth (Lin & Chen, 2014).

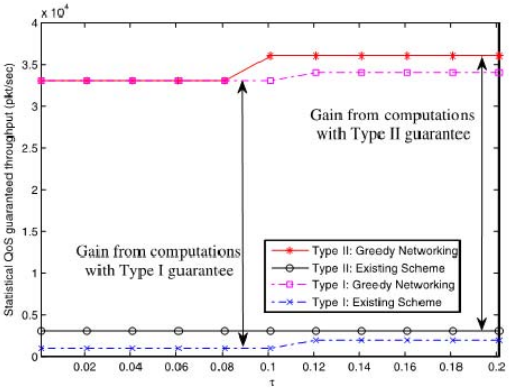

Figure 2: 10 dB gain of throughput under statistical warrantee of QoS is achieved (Lin & Chen, 2014)

This project contributes the highest volume of technical publications in IEEE Xplore, in the category of machine-to-machine communication, and couples of highly visible publications listed into IEEE Xplore Popular. At this time, we are developing more operating networking algorithms in the machine swarm, which can be extremely useful in open-loop communication technology for wireless infrastructure too. As suggestion from in-network computation, this research shall enable a new computing platform of M2M communications.

References and Further Reading

1. W.C. Ao, S.M. Cheng, K.C. Chen (2012, Feb). Connectivity of Multiple Cooperative Cognitive Radio Ad Hoc Networks. *IEEE Journal on Selected Areas in Communications*, vol. 30, no. 2, pp. 263-270.
2. K. C. Chen, S. Y. Lien (2013, Mar). Machine-to-machine communications: Technologies and challenges. *Ad Hoc Networks*.
3. K.C. Chen, M. Chiang, H. Vincent Poor (2013, Sep). From Technological Networks to Social Networks. *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 9, pp. 548-572.
4. I.W. Lai, C.H. Lee, K.C. Chen, E. Biglieri (2014, Jan). End-to-End Virtual MIMO Transmission in Ad Hoc Cognitive Radio Networks", *IEEE Tr. on Wireless Communications*, vol. 13, no.1, pp. 330-341.
5. S.Y. Lien, K.C. Chen, Y. Lin (2011, Apr). Toward Ubiquitous Massive Accesses in 3GPP Machine-to-Machine Communications. *IEEE Communications Magazine*, vol. 49, no. 4, pp. 66-74.
6. S.Y. Lien, S.M. Cheng, S.Y. Shih, K.C. Chen (2012, Sep). Radio Resource Management for QoS Guarantees in Cyber-Physical Systems. *IEEE Transactions on Parallel and Distributed Systems*, vol. 23, no. 9, pp. 1752-1761.
7. S.C. Lin, K.C. Chen (2014, Mar.) "Improving Spectrum Efficiency via In-Network Computations in Cognitive Radio Sensor Networks", vol. 13, no. 3, pp. 1222-1234, *IEEE Tr. on Wireless Communications*.

Intel-NTU Connected Context Computing Center

BL-7C, Barry Lam Hall, 1 Roosevelt Road, Sec. 4
National Taiwan University, Taipei, 10617 Taiwan
Tel: +886-2-3366-1467

http://ccc.ntu.edu.tw

About the Author

Kwang-Cheng Chen, Distinguished Professor,

Department of Electrical Engineering, National Taiwan University

SIGARC PI, Intel-NTU Connected Context Computing Center

Acknowledgments

This work was jointly supported by National Science Council, National Taiwan University and Intel Corporation under Grants NSC102-2911-I-002-001 and NTU103R7501-1.