Flexible Spectrum Management for M2M Wireless Networks

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Properties of M2M Networks

- Large amount of machines
  - Spectrum demand per unit area is high
  - Network access could be a problem
- Heterogeneity
  - Machine size and complexity
  - Communication demands
  - Mobility
  - ....
- Local correlation
  - Correlated observation
  - Correlated radio environment

Communication Support for M2M

- Wireless is better
  - No need for so many wires
  - For mobile devices
  - Easier configuration
- Problems
  - Not enough spectrum
    - Coexistence issue
  - Interference in the environment
    - Interference mitigation
  - Heterogeneous communication behaviors
    - Signal pattern design
    - Spectrum management

Opportunities

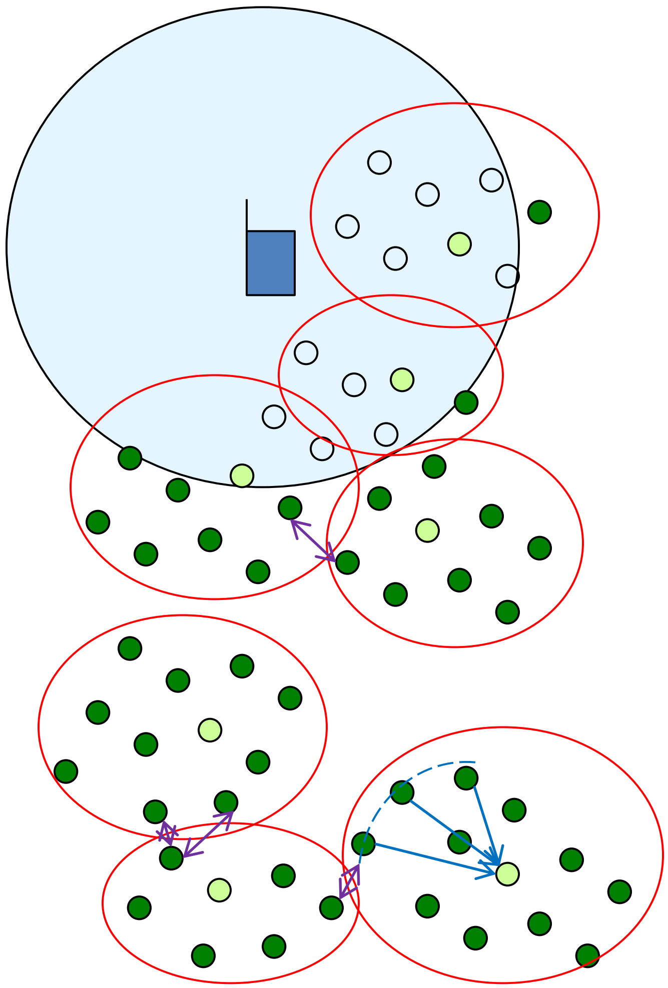
- Human communication is not always active
  - Recent technology: cognitive radio
- Correlated observation
  - Distributed coding
- Local data aggregation points
  - Analyze and buffer data – reduce traffic
  - Reduce machine power
  - Frequency reuse
- Interference management
  - Distributed interference alignment

Ongoing Wireless M2M Efforts

- WAN: LTE, WiMAX
  - Optimized for human-to-human (H2H) applications
  - Not able to support large number of machines in limited spectrum
  - New efforts initiated
    - LTE-Advanced: Machine Type Communications (MTC)
    - WiMAX 2.0: IEEE 802.16p
- LAN and PAN: WiFi, Bluetooth, Zigbee
  - Can/already handle M2M applications
  - Work in a small area, not scalable to large area
  - New efforts: IEEE 802.11ah (long range)
- Still need to design
  - Flexible spectrum usage
  - Supporting large number of machines with backward compatibility
  - Considering machine behaviors and correlated observation
  - Efficient frequency reuse

New Technologies for M2M

- Clustering
  - Frequency reuse
  - Decentralized opportunistic access
- Flexible waveforms and frequency reuse
- Distributed coding
- Interference mitigation



Clustering (1)

- Machines form smaller clusters and transmit to “cluster heads”.
  - Short range, power saving, frequency reuse.
- Cluster heads perform multi-hop transmission to the data collection center.
  - Scalable, not dependent on or limited by the fixed wired spots.
- Machines sense to avoid interfering or being interfered by H2H communications.
  - Decentralized spectrum access, interference off-loading.
- Comparable to the concept of traffic off-loading in the next-generation cellular networks to deploy smaller pico or femto cells.
  - Clustering is more flexible, does not need network planning.

Clustering (2)

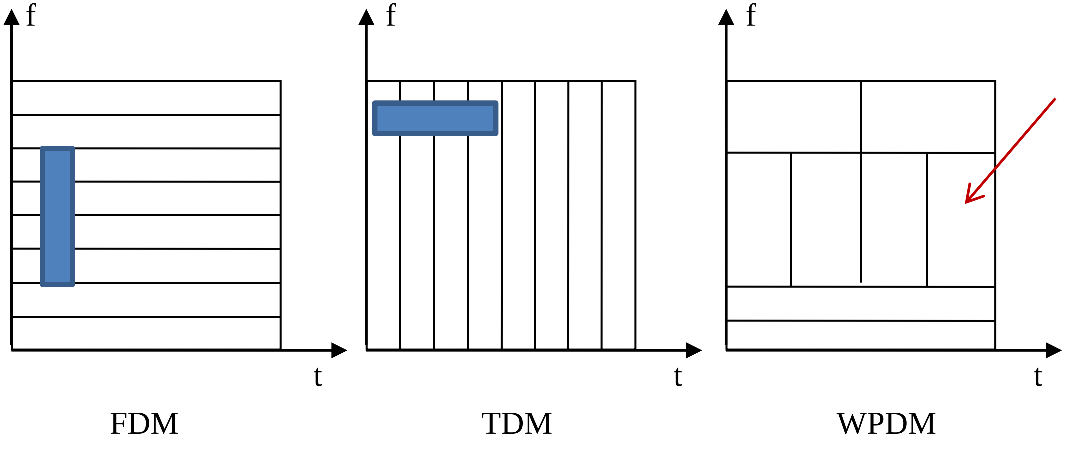
- Consideration of correlated observation
  - Lower transmission power and spectrum in the same cluster
- "Umbrella clusters"
  - Reduce frequency of handover
  - Easier waveform design

- Consideration of ambient noise/interference
  - Spectrum map
- Consideration of good interference mitigation techniques
  - Increase multiplexing gain per unit

Flexible Waveforms

- Fixed configuration of time slots, subcarriers, or orthogonal codes as resource blocks (RB) are not flexible enough, and can not handle different interferences and device mobility well.
- Flexible radio resource division
  - E.g., wavelets as basis functions (wavelet packet division multiplexing)

Impulse interference affects many subcarriers, narrow band interference affects many time slots, But they only affect one RB in WPDM.

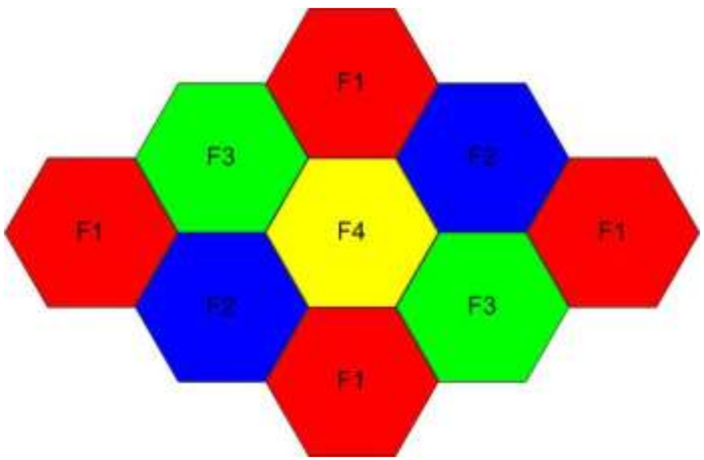


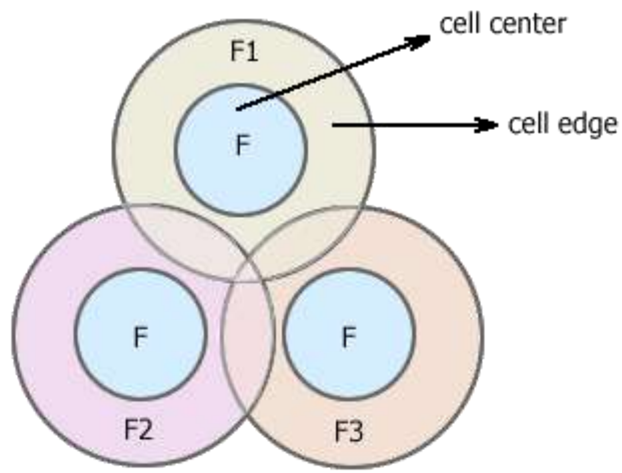
High mobility device needs wider BW to account for BW expansion due to Doppler, but usually has shorter transmission due to shorter coherence time.

Flexible Frequency Reuse

Conventional reuse

- Whole cell, whole spectrum reuse
- Partial cell, partial spectrum reuse





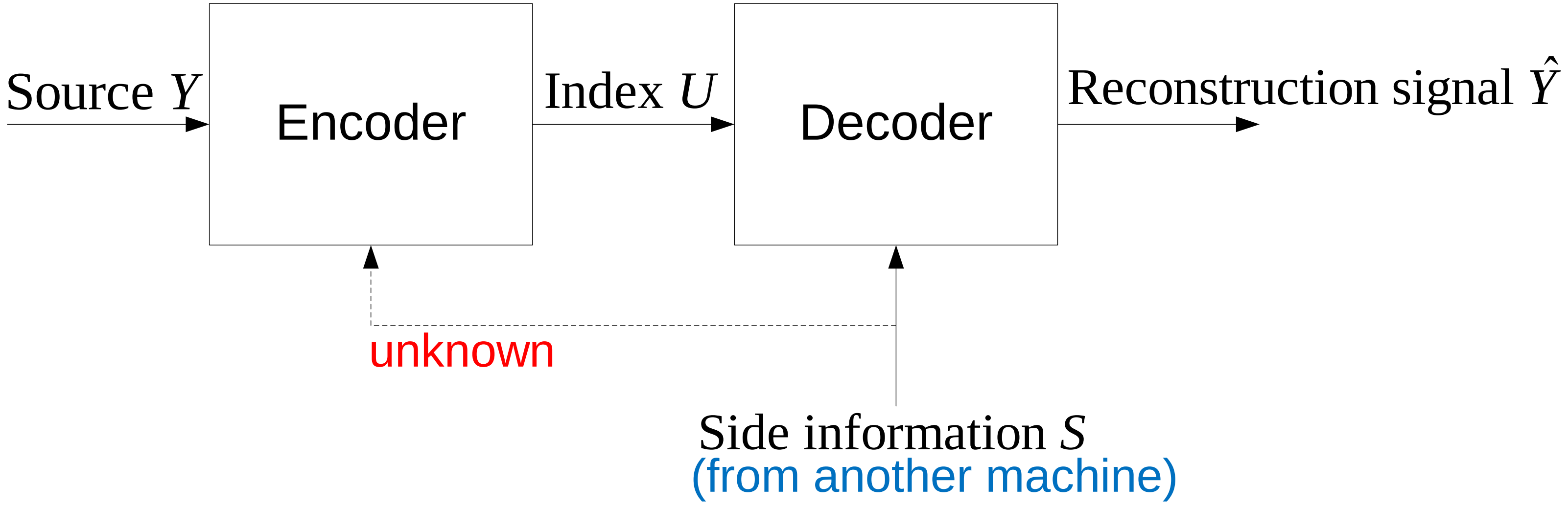
- For dense networks in a small area, especially operating at very high frequency and wideband, the reuse pattern depends on not only distance but also frequency.

A more flexible approach

- Interference sensing based per RB reuse.

Distributed Coding

- Distributed source coding for correlated data.
  - Wyner-Ziv Coding: source coding with receiver side information



- Distributed channel coding for spatial diversity

Interference Mitigation

- Inter-cluster interference mitigation to achieve high multiplexing gain per unit area
  - Soft frequency reuse, adaptive frequency reuse
  - Coordinated transmission/scheduling
  - Interference alignment and cancellation
- Machine-human interference
  - Interference sensing and opportunistic access

Case Study

- Exemplary scenario: Smart electric meters
- Baseline system 1: random access channels (RACH) [1]
  - PRACH Configuration Index 6 in LTE
    - 200 RACH opportunities/s/preamble
  - H2H usage is 90% (peak hours, office buildings) and has higher priority
    - On average 6.4 preambles accessible by machines (1280 RACH opportunities/s)
    - 1% collision probability – can support 12.8 RACH intensity
      - Can support max 3840 meters with 5 min reporting periodicity
      - When the meters are synchronized within 10s, can only support 128
  - Both numbers are much lower than 35670, the number of meters in a 2km macro cell in urban London

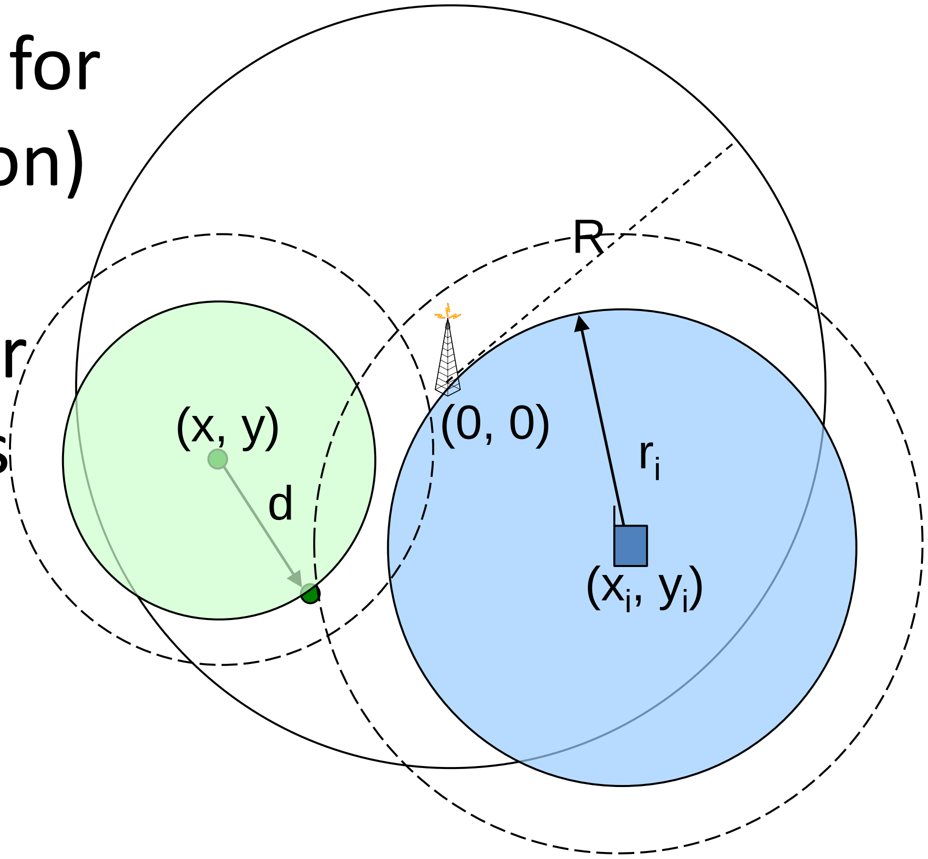
[1] "Study on RAN Improvements for Machine-type Communications," 3GPP TR 37.868, Sep. 2010.

Case Study (cont.)

- Baseline system 2: pico or femto cell deployment
  - Assume wired connection is available wherever a pico or femto BS is deployed.
  - No interference sensing and opportunistic access. 90% spectrum pre-allocated to macro cell, and 10% pre-allocated to pico or femto cells.
- Simulation settings
  - AWGN: -100 dBm
  - Path loss (dB) = 130.19 + 37.6 * log(R)
  - SNR requirement for machines: 5 dB
  - SNR requirement for machines for H2H: 10 dB
  - Frequency reuse one (perfect interference mitigation) for pico, femto cells and for clusters
  - Machines have correlated data. Distributed coding reduces 3dB transmission power.

Uplink Scenario

- H2H is uplink power controlled.
- Machines will interfere the BS if the BS is covered by the interference radius of a cluster (including a safe margin for another 20dB attenuation)
- H2H will interfere the machines in a cluster if the cluster is within its interference radius (dashed circle)



Uplink Scenario

Tx power (dBm)	-3	0	32	35	46.5
Cluster radius (km)	0.0965 (Dist. coding)	0.1159	0.8225 (Dist. coding)	0.9884	2 (Baseline 1)
Number of machines (Baseline 2)	429.54X	297.78X	5.92X	4.09X	X (=3840 or 128)
Number of machines	625.7X	433.6X	8.7X	6X	-

- Clustering and interference mitigation increase the number of machines exponentially.
- Sensing and opportunistic access improve another 40%-46%.
- Distributed coding improves another 44%.

Downlink Scenario

Tx power (dBm)	-3	0	32	35	46.5
Cluster radius (km)	0.0965 (Dist. coding)	0.1159	0.8225 (Dist. coding)	0.9884	2 (Baseline 1)
Number of machines (Baseline 2)	429.54X	297.78X	5.92X	4.09X	X (=3840 or 128)
Number of machines	600.5X	416.2X	8.3X	5.8X	-

- Similar performance improvements as the uplink scenario.

Issues for Discussion

- Are cellular systems good platforms for supporting M2M communications?
- Pros and cons of dedicated resource (channels) vs random access.
  - Depends on machine traffic model.
  - How does data aggression or buffering help?
- How to form machine clusters?
  - Location based, mobility based, application based?
- Is interference alignment really applicable?