M2M massive wireless access: challenges, research issues, and ways forward

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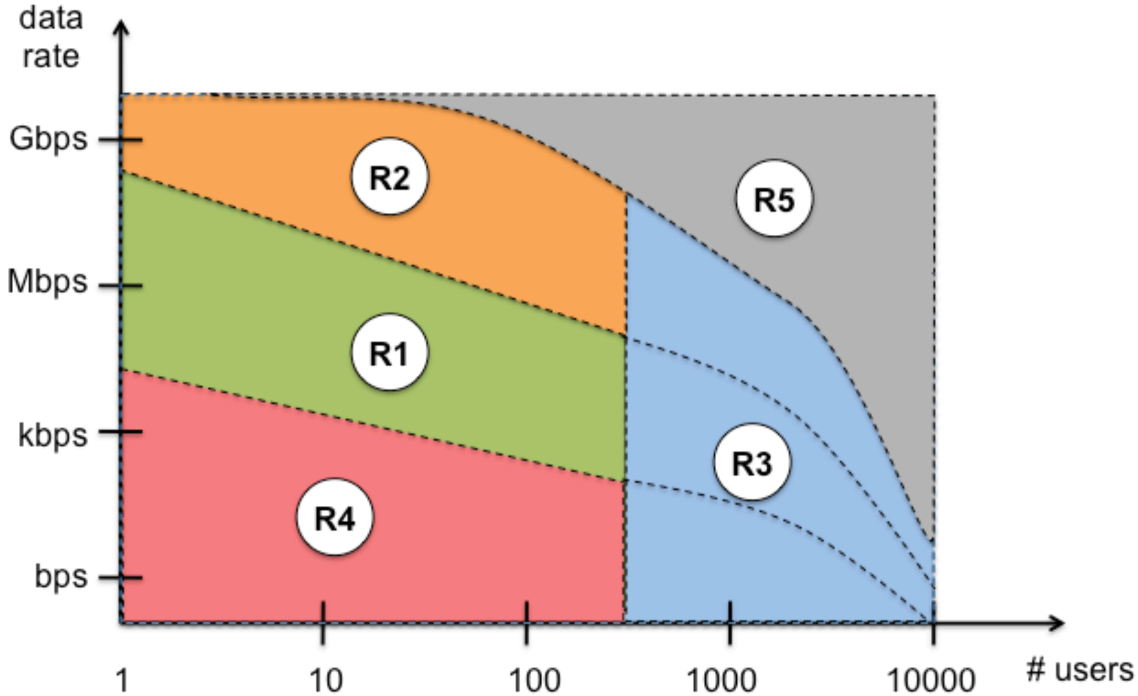
the shape of wireless to come



R1: today's systems

R2: high-speed versions of today's systems

R3: massive access for sensors and machines

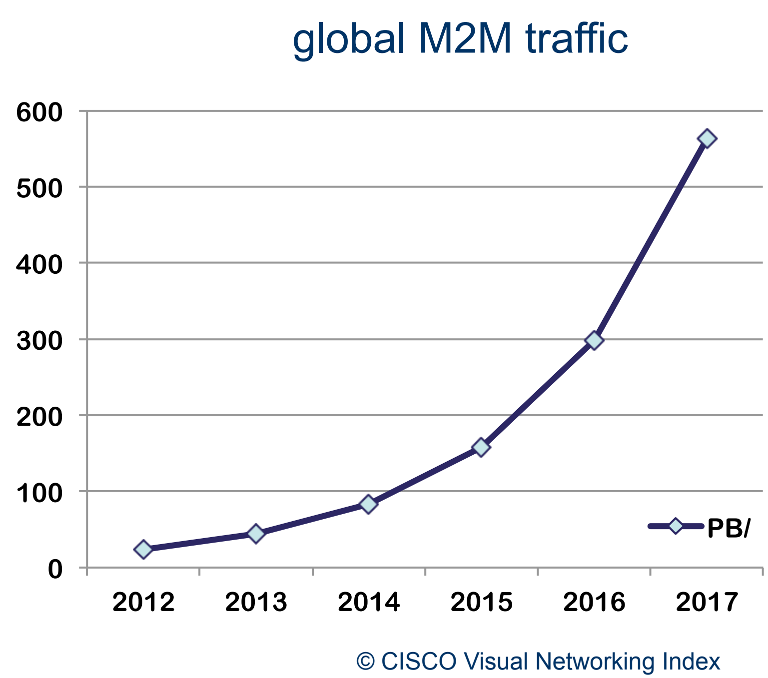
R4: ultra-reliable connectivity at minimal rate

R5: physically impossible

5G=R1+R2+R3+R4

enormous M2M growth expected

- 24-fold **traffic growth** from 2012 to 2017



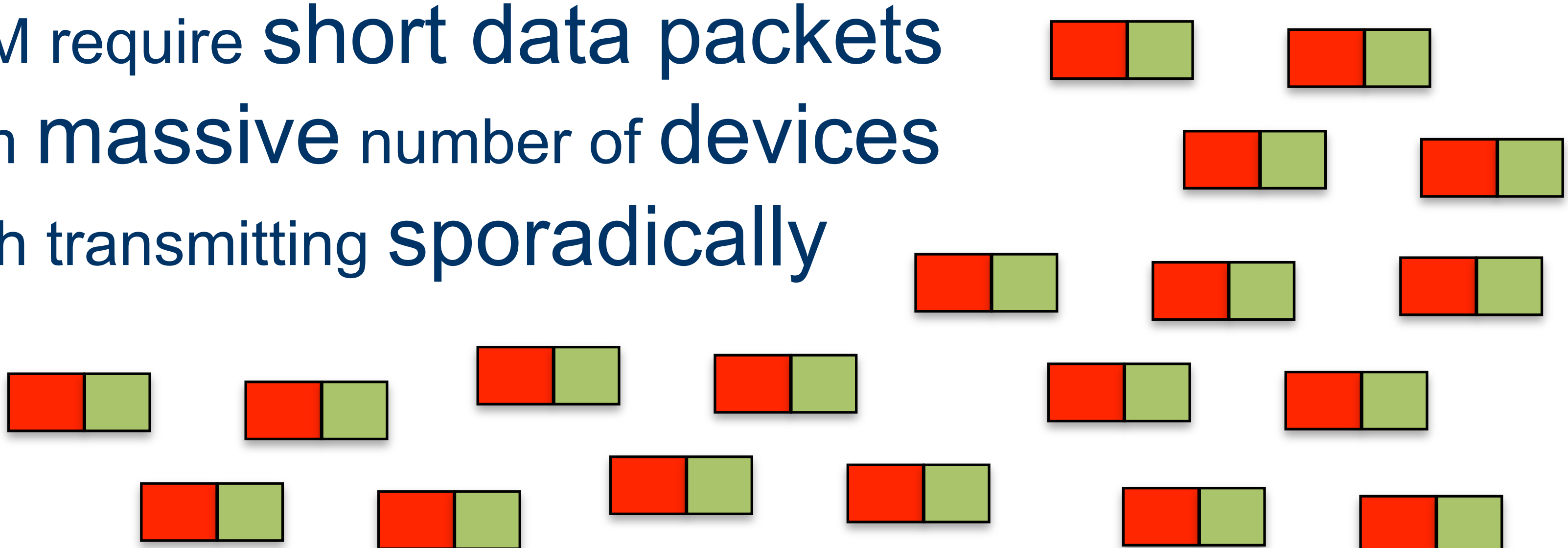
- 4.6-fold **growth of M2M #subscriptions** from 369 million in 2012 to 1,7 billion in 2017

- M2M traffic will account for approximately **5 %** of **overall mobile traffic** in 2017

high-speed wireless vs. M2M wireless

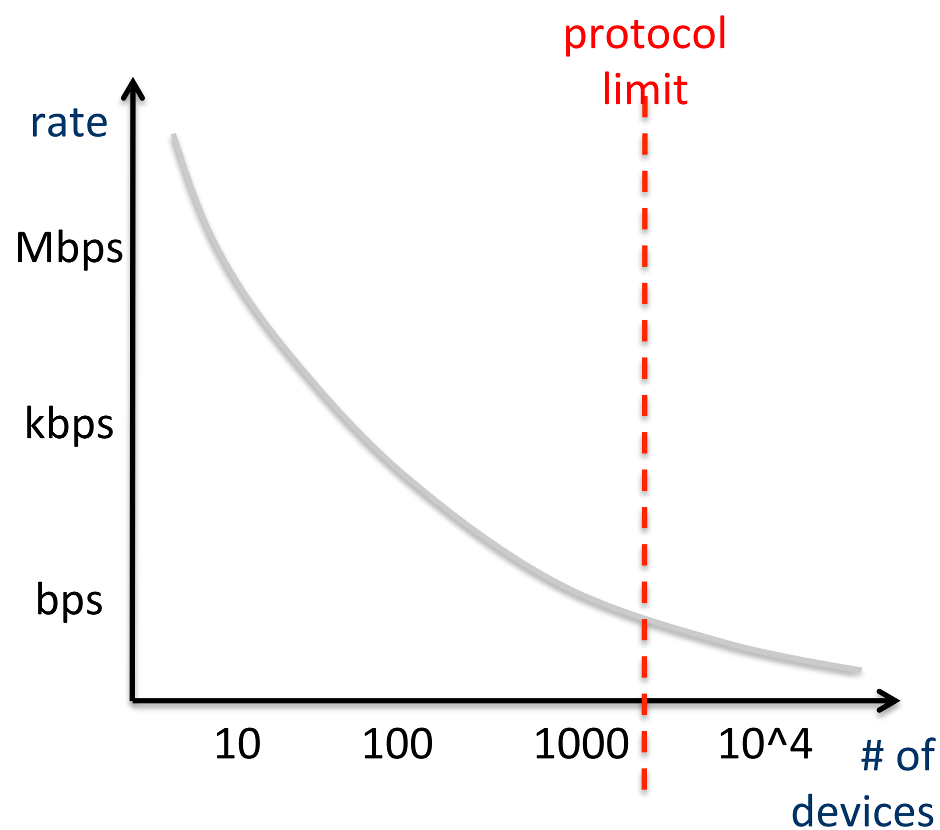
- high-speed systems built from information-theoretic principles with small control info and large data

- M2M require short data packets from massive number of devices each transmitting sporadically



wireless M2M challenges

- small amount of data sporadically
  - signaling to maintain connection becomes an issue
- access from
  massive number of devices
  - scheduled or random
    or hybrid or…
  - scaling protocols
    towards
    more devices (lower rates)



wireless M2M challenges

- correlation of sensor data across space and time
  - better scalability if properly used
- radically new frame structure
  - highly reliable connections despite coverage problems
  - low latency
  - long battery lifetime

MPR AND SIC FOR MASSIVE ASYNCHRONOUS ACCESS

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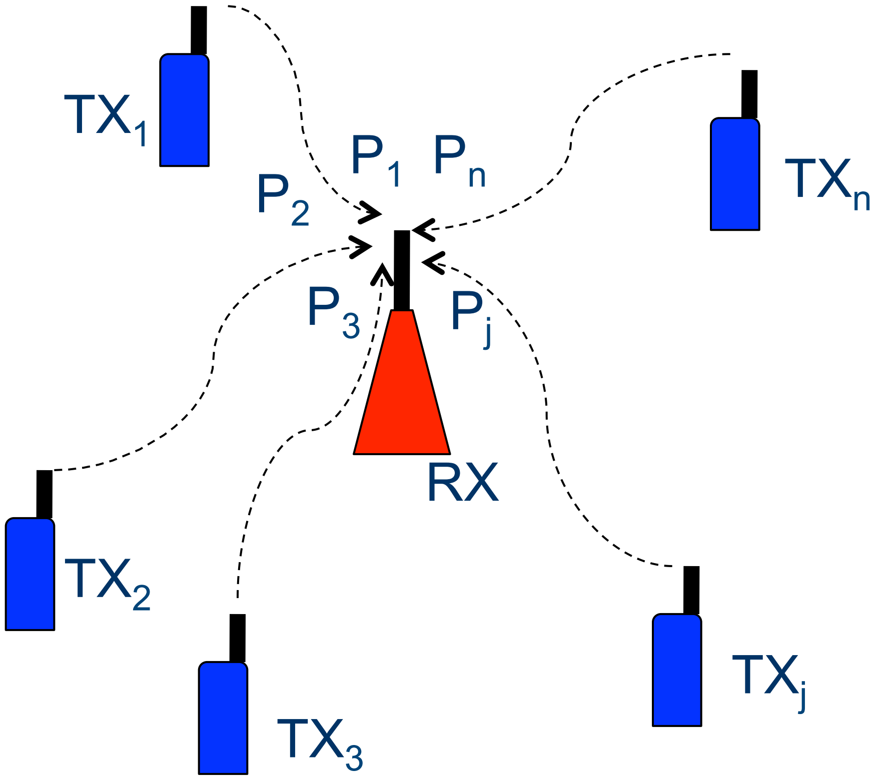
massive asynchronous access

- approach
  – put the complexity burden on the Base Station
  – use of
  SIC successive interference cancellation

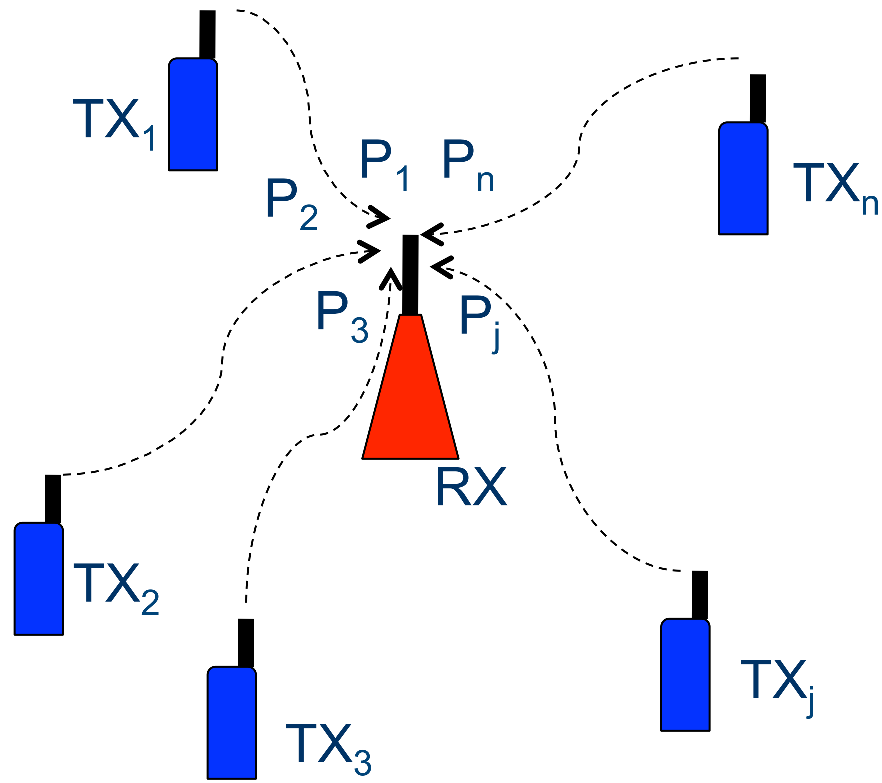


- key techniques
  – multi-packet reception (MPR)
  – coded random access
  – coded reservation

advanced MPR functionalities

Uplink in wireless cellular networks

- Multiple transmitters sharing same wireless link
- Mutual interference can generate packets collision



Decoding model: SINR threshold

- Use of strong coding to achieve Shannon capacity
- P_j : power of the *j*-th signal at the receiver
- N_0: noise power (neglected)
- g_j : SINR of the *j*-th signal
- b : capture threshold

Aggregate interference

$$\gamma_j = \frac{P_j}{I + \cancel{N_0}}$$

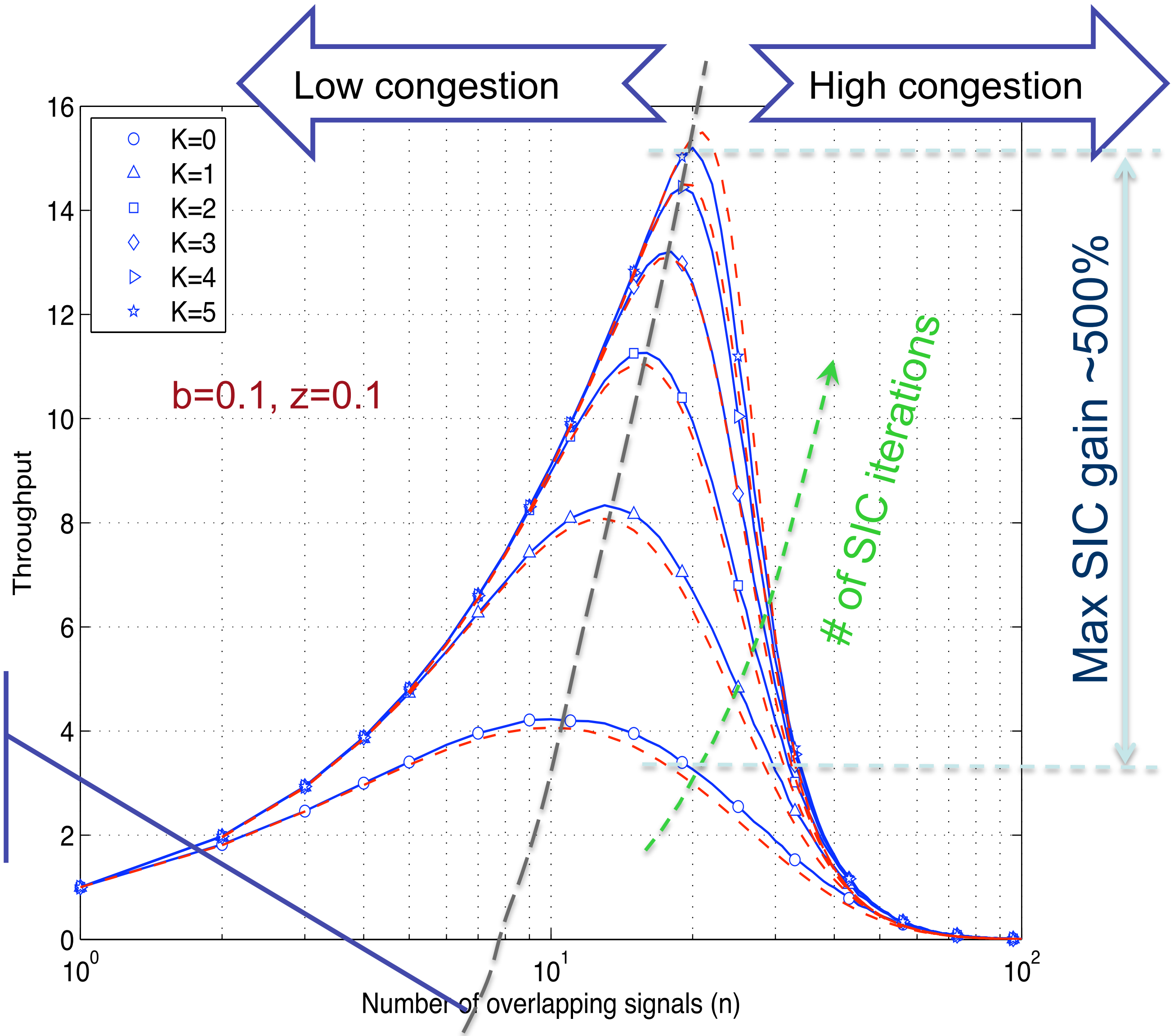
g_j > b \ *j*-th signal is correctly decoded (capture)

g_j < b \ *j*-th signal is collided (missed)

Multi Packet Reception

- MPR can be enabled by means of
  - signal spreading (DSSS)
    - $b<1 \rightarrow$ multiple signals (up to $1/b$) can be captured at a time
  - successive interference cancellation (SIC)
    - capture signal j with SINR $g_j>b$
    - reconstruct and cancel signal j from the overall received signal
      - cancellation leaves a fraction z of residual interference power
    - repeat iteratively

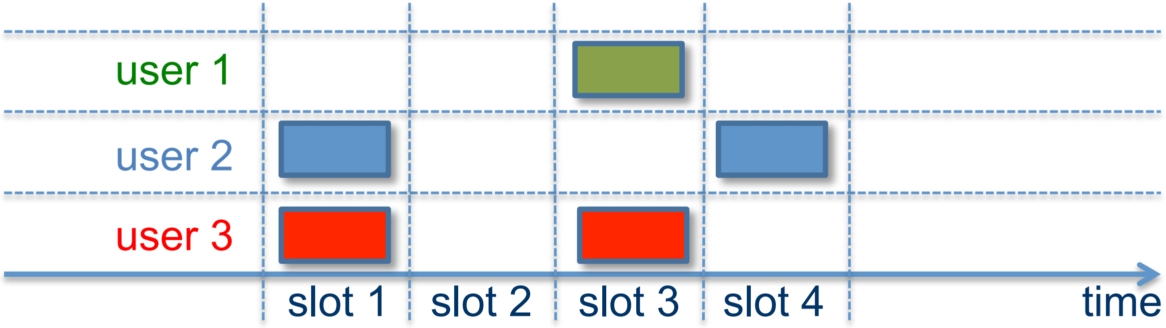
SIC+MPR throughput



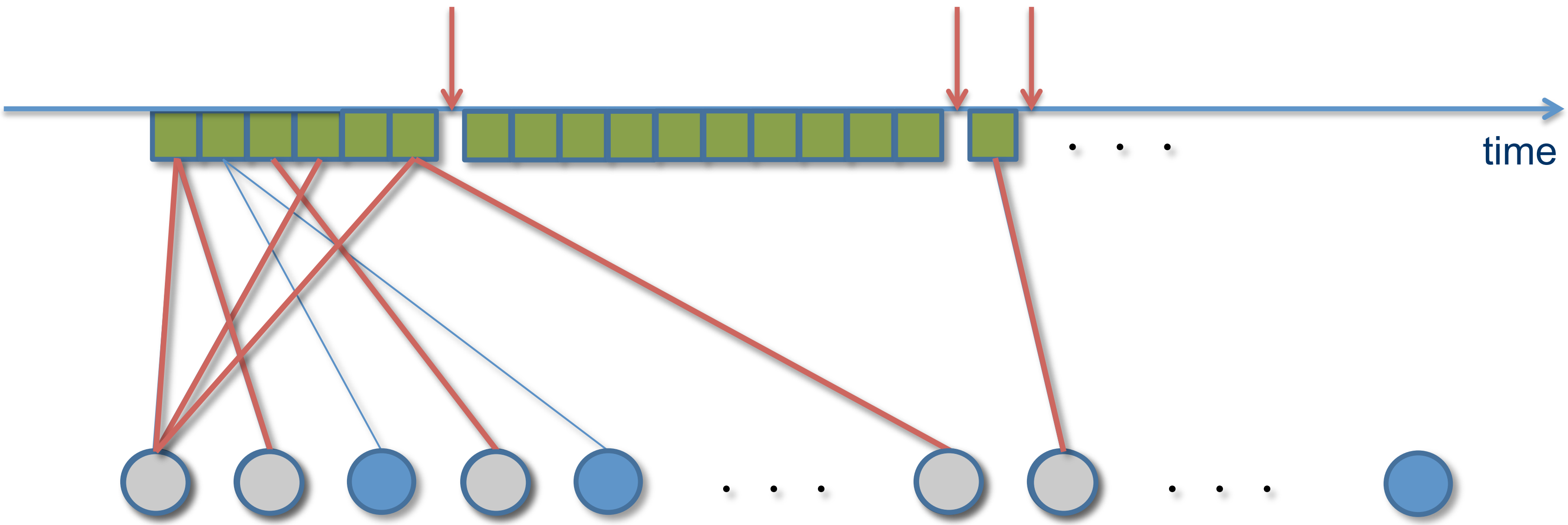
optimal # of concurrent transmissions

beyond ALOHA: coded random access

- each user sends randomly multiple replicas
- each successfully decoded replica enables canceling of other replicas



frameless ALOHA



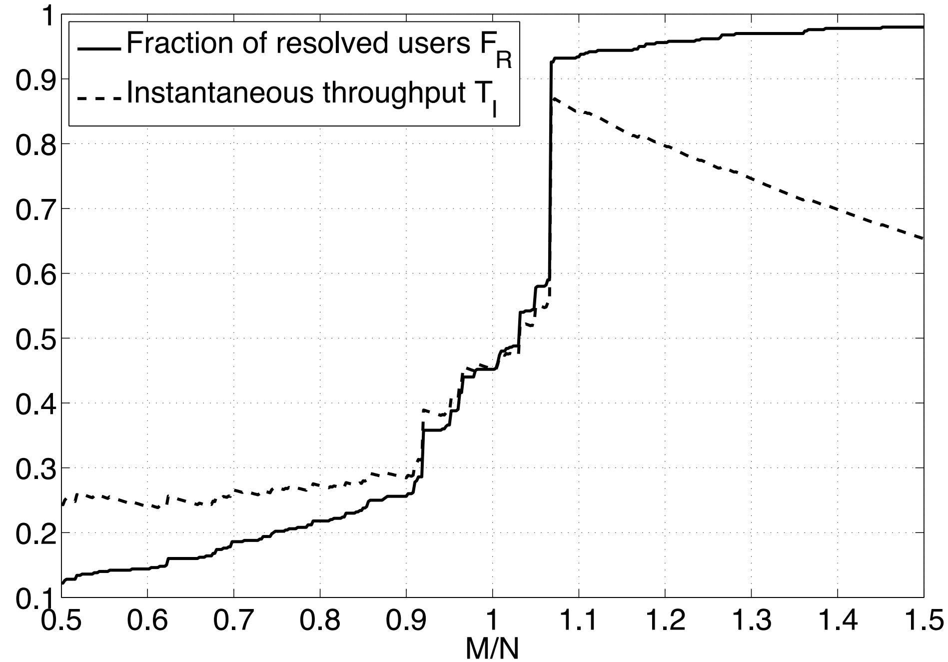
- single feedback used after M-th slot
  - –M not defined in advance
- feedback when sufficient slots collected
  - –maximize throughput
  - –random access operates a rateless code

frameless ALOHA
stopping criterion

a typical run of frameless ALOHA in terms of

(1) fraction of resolved users

(2) instantaneous throughput



heuristic stopping criterion:
fraction of resolved users

genie-aided stopping criterion:
stop when T is maximal

termination and throughput

- simple termination

stop the contention
if either is true

$F_R \geq V$ or $T=1$

- genie-aided (GA) termination

N	50	100	500	1000
T_{GA}	0.83	0.84	0.88	0.88
T	0.82	0.84	0.87	0.88
F_R	0.75	0.76	0.76	0.76
M/N	0.97	0.95	0.9	0.9
β	2.68	2.83	2.99	3.03
V	0.83	0.87	0.88	0.89

EXPLOITING SIGNAL CORRELATION TO SUPPORT MASSIVE M2M ACCESS

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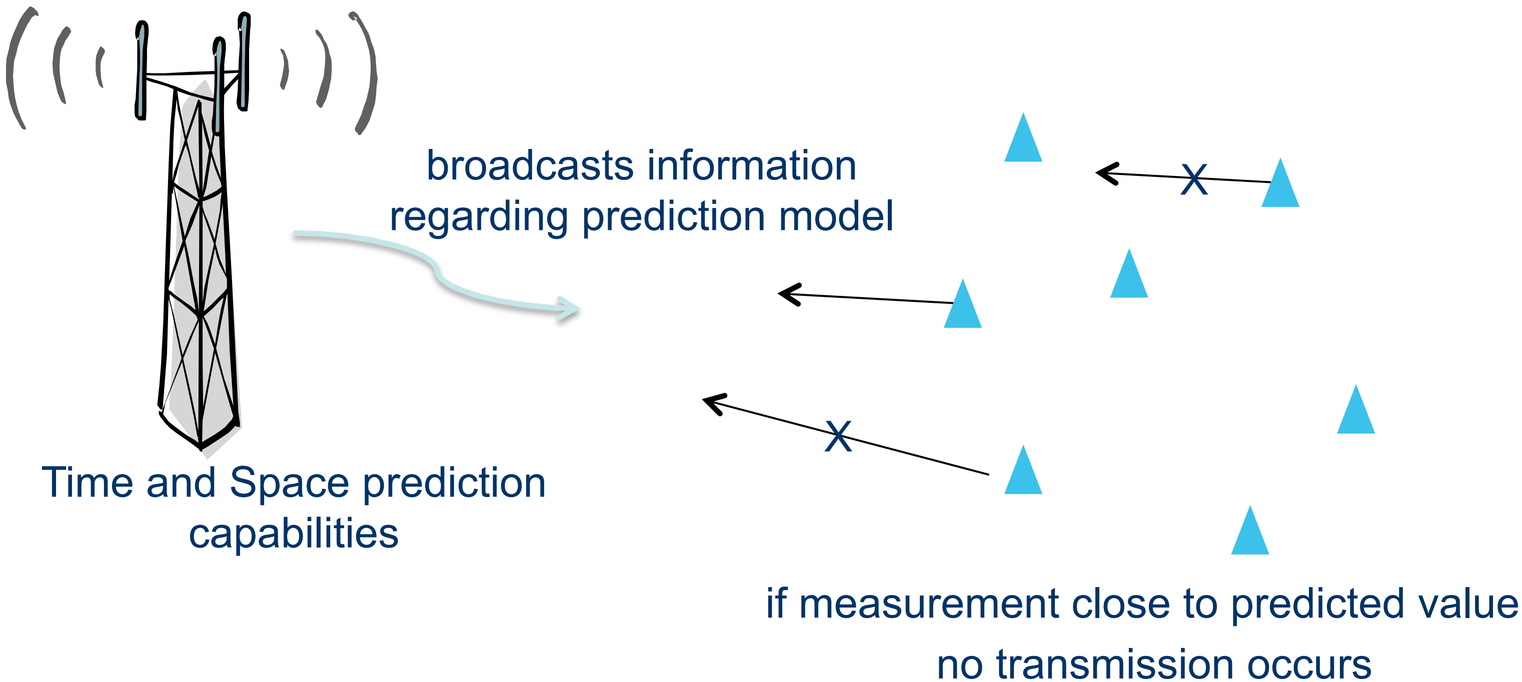
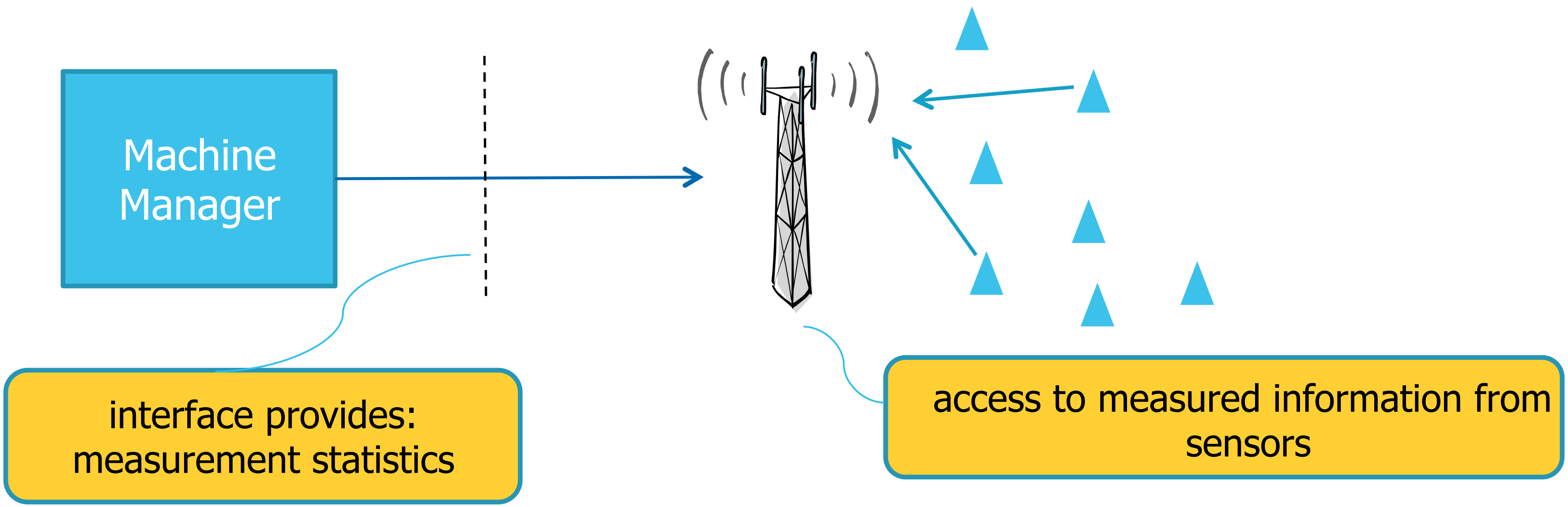
many machine signals predictable in space and time

current cellular communications (human based communicaitons)	M2M perspective (measurement applications)
peer to peer communications	many nodes to sink
aim of communication: receive information of an individual	sink has to extract a representation out of many devices measurements
signals are unpredictable	measurements can be predicted
signals between smartphones are uncorrelated	node correlation (e.g.) via spatial location)



- despite the massive deployment of machines,
the amount of transmissions can be reduced with proper management

- effective amount of transmitting machines can be significantly reduced



• interface between Machine Manager and network can be created for improved prediction (statistics of measurements);

• potential to:

❑ support of more machines;

❑ longer battery life due to reduced transmission

❑ operator offers added value to the Machine Manager by providing improved statistical information about inferred environment.

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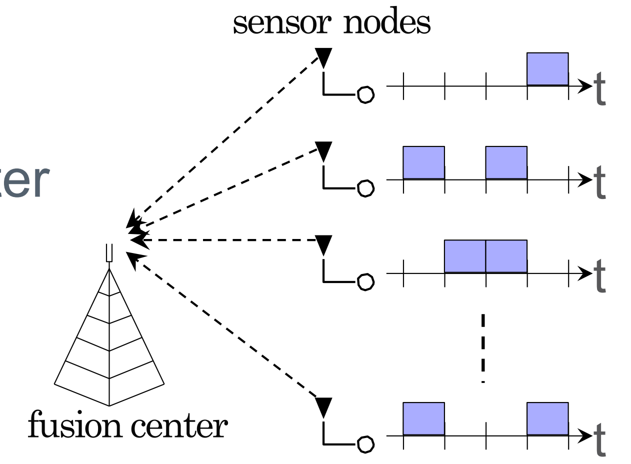
EXPLOITING SPORADIC COMMUNICATION AT THE PHYSICAL LAYER

compressed sensing multi-user detection

- motivation
  - massive machine communication with reduced control signaling overhead through advanced PHY processing at fusion center

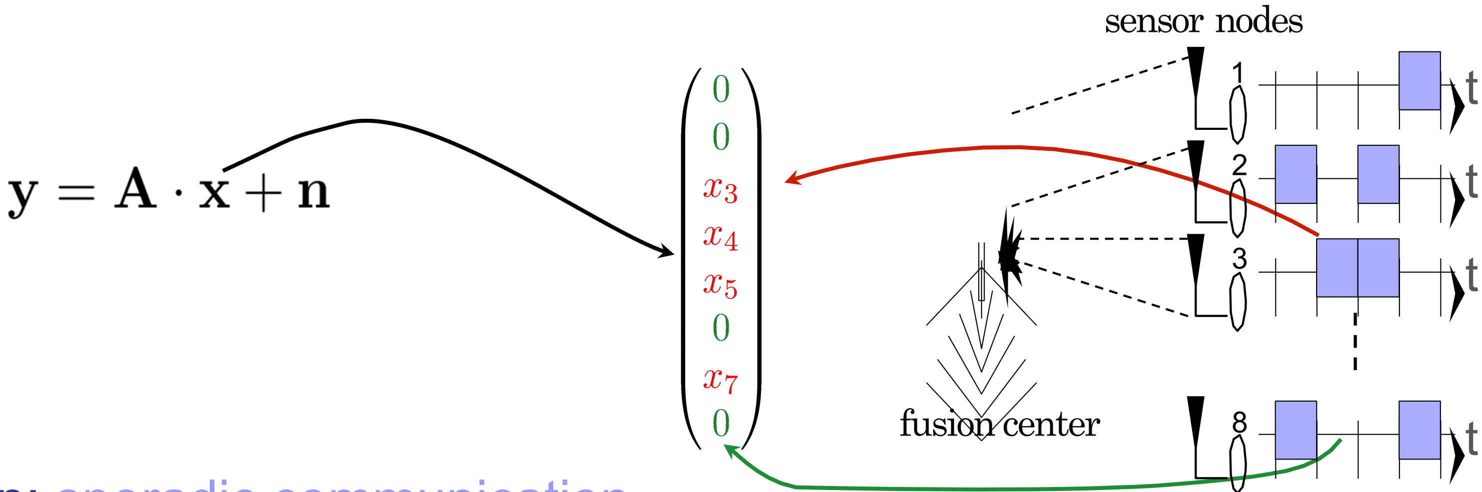


- system assumptions
  - uplink sensor communication to fusion center
  - massive number of devices
  - sporadic activity & low-data rates
  - non-orthogonal random medium access

- key features
  - compressed sensing multi-user detection exploiting sporadic activity for **joint activity and data detection**
  - enabling efficient random access with very simple devices

general problem and approach

- problem: how to recover the sensor data and activity from observations?



- assumption: sporadic communication
  - inactive nodes “transmit” only zeros
  - active nodes transmit data symbols

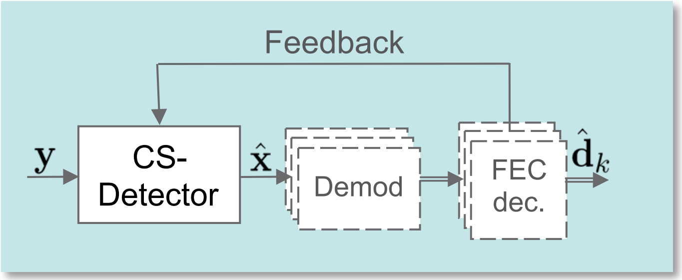
  → **the multi-user vector is sparse**

- idea: exploit sparsity in detectors to allow for **activity detection**

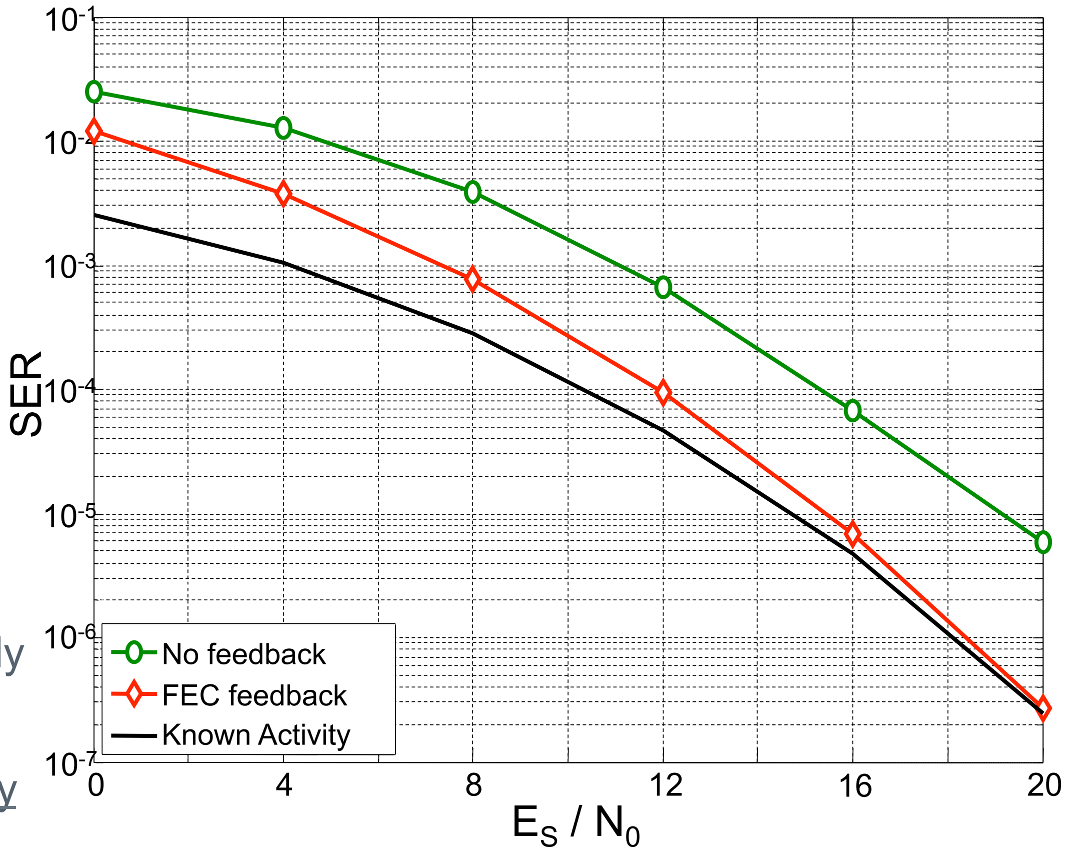
exemplary results: CS-MUD with FEC

- idea: tailor CS algorithms to communications context

  example: FEC feedback



- classic detection:
  - access reservation & scheduling
  - known activity: data detection only
- conclusions:
  - CS algorithms enable joint activity and data detection
  - no access reservation & scheduling → adapted CS-MUD is a promising technology for massive M2M



CDMA System with K=128 users, N=32 spreading sequence length, Activity probability 2% per user, BPSK symbols, Frames with 50 information symbols, [5;7] convolutional code

CS detection: Group Orthogonal Matching Pursuit (GOMP)

(wireless) road ahead for M2M

- need for consolidated understanding of the fundamentals in control signaling for
  - massive access
  - short packets
  - extremely variable transmission patterns

- maximize the number of serve users under severe battery and complexity constraints

- integration with the non-M2M traffic