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Signal processing: a networking perspective Part 2 – option B

Andrea Zanella

zanella@dei.unipd.it

SIGnals processing &
NETworking research group

PhD Summer School of Information Engineering – 7-11 July, 2014 – Brixen (BZ)

Outline

- **Part 3: QoE-oriented networking**
  - Mixing up PHY and application-layer signals
    - smart environments
  - Context awareness from signal processing
    - SSIM characterization of video content
    - Handover optimization
  - Bye bye!

http://www.keepcalm-o-matic.co.uk/p/keep-calm-it-s-lunch-time/

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Exploiting complementarities

Wireless Sensor Nodes (WSN)

- Pros
  - Low cost
    - Large networks with many devices
  - Low energy consumption
    - Possibility to power with small batteries or energy-scavenging
- Cons
  - Limited computing capabilities
  - Limited memory
  - Limited transmission range/speed

Autonomous Mobile Robots (AMR)

- Cons
  - High cost
    - Single or few units
  - High energy consumption
    - Need for large batteries and/or recharging stations
- Pros
  - High computational capabilities
  - Large memory
  - Large energy capacity
  - Large transmission range/speed
  - Advanced mobility

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Application scenarios

Application Scenarios

- Smart Environments
  - AMRs may catalog, localize and retrieve objects upon request
  - Libraries: AMRs may put back books on the shelves after closure
- Assisted Living
  - A portable device may drive a visual-impaired person through a partially unknown environment by vocally describing the smart objects that recognizes along the way
  - A personal robot may display to a motion-impaired user the list of smart objects that it discovers
    - remote controls, mobile phones, books, …

Limit of existing solutions

- Dataset of object-models stored on the robot
  - Low flexibility: new objects shall be included in the directory to be recognized
  - Similar objects are indistinguishable
- RFID-based communication
  - Cheaper, but requires physical proximity and does not support sophisticated algorithms nor multi-hop communication

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Target application: autonomous exploration of unknown "smart" environments

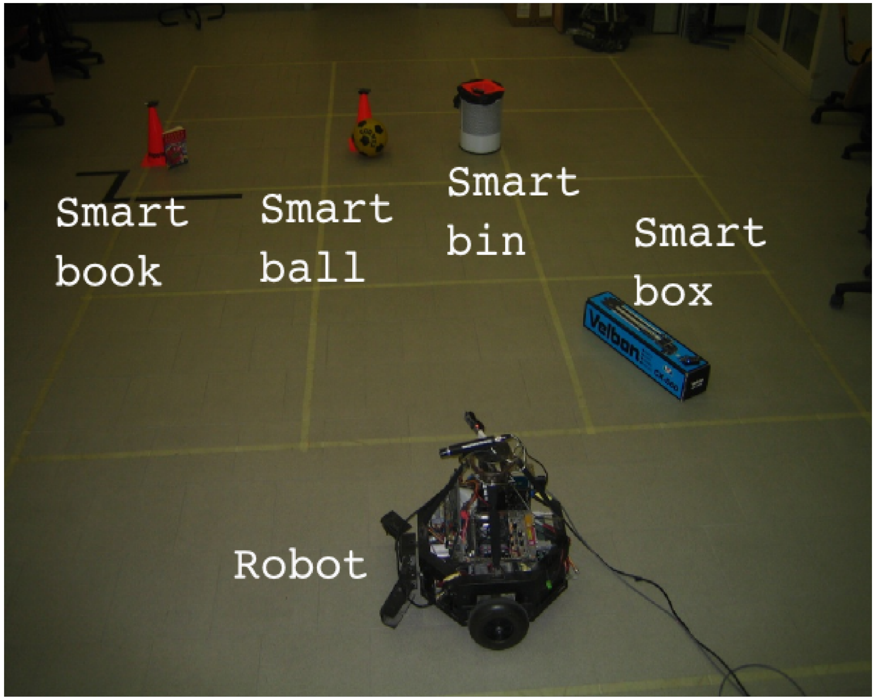
Vision

- AMR equipped with
  - odometers for self-localization
  - on-board camera
  - RF transceiver

- Smart Objects (SOs), i.e., common objects tagged with WSNs that provide
  - Computational/communication capabilities
  - data storage
  - self-management features

Goal

- Autonomous **exploration** of **unknown environments** and **interaction** with SOs
  - No prior info about the number or kind of SOs



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Experimental Set up

TmoteSky sensor nodes

- 250 kbps @ 2.4 GHz
- Ultra low current consumption
- Light, temperature, RSSI sensors
- TinyOS

AMR Bender

- Home-made, based on Pioneer 2 ActivMedia platform
- Linux OS with Miro middleware
- ATX motherboard
  - 1,6 GHz Intel Pentium 4, 256 MB RAM, 160 GB HD
- On-board camera
- Odometers

TmoteSky connected to ATX via USB + MoteService class added to Miro

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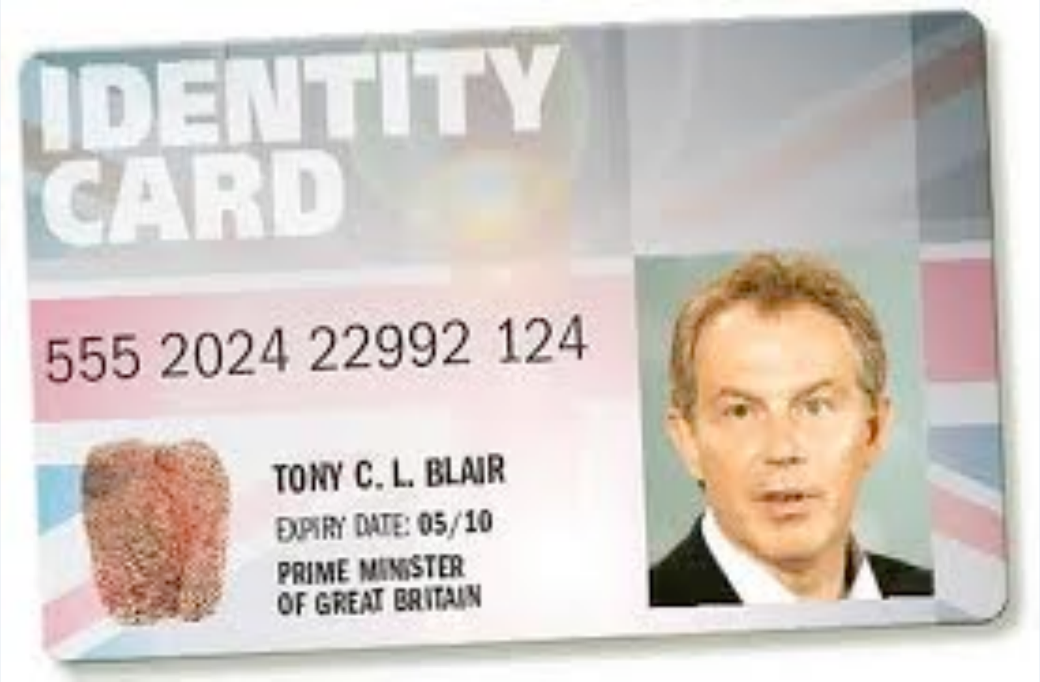
System's building blocks

1. Smart Object Identification
   - The AMR gets a list of close by SOs, but does not know their location
2. Smart Object Mapping
   - The AMR builds a map of the area estimating SOs' location
3. Smart Object Recognition
   - The AMR gets close to a selected object and, then, visually recognizes it in the image taken by the on-board camera



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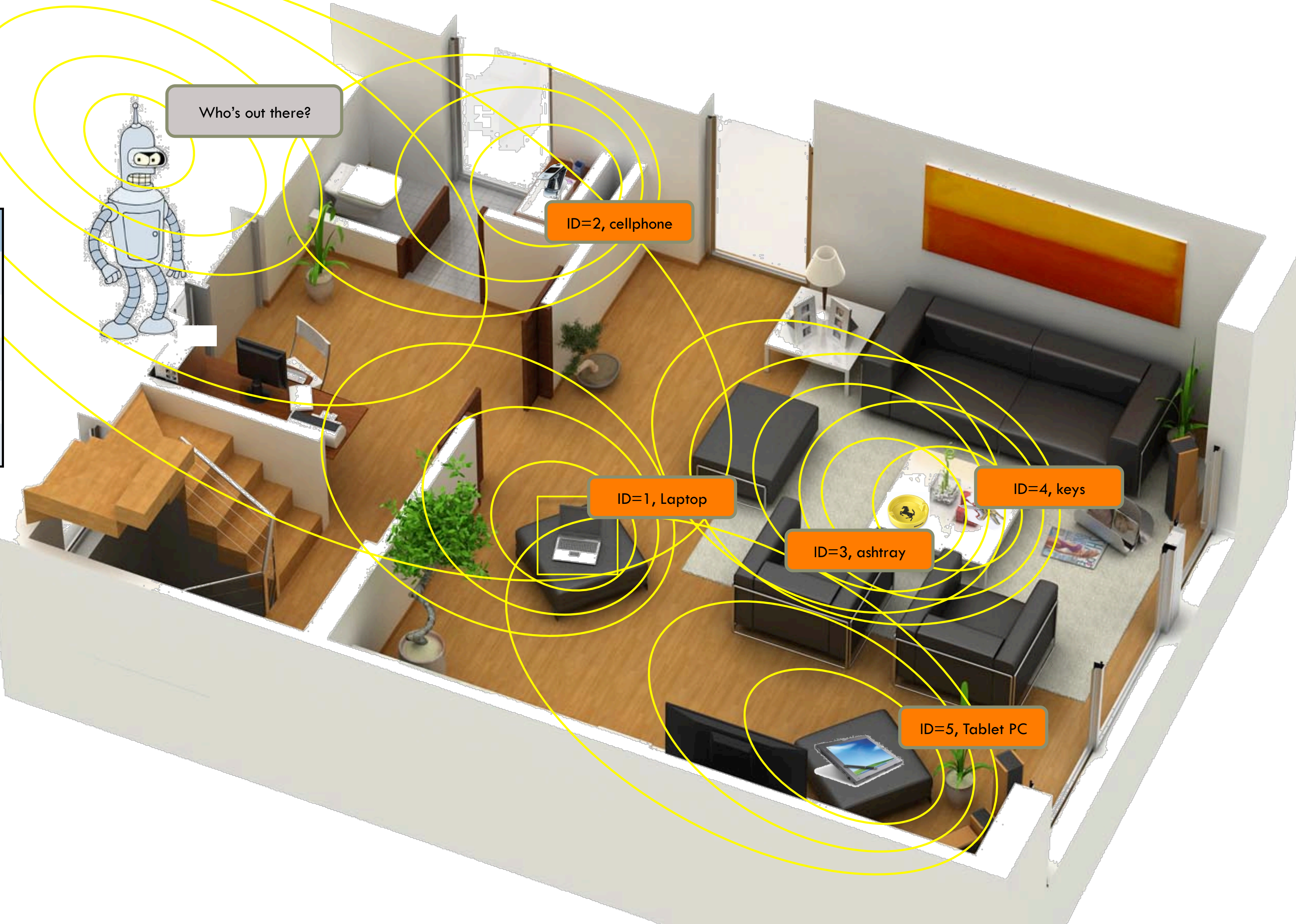
Step 1. Smart Objects Identification

Identification: centralized approach

Smart Objects Lists

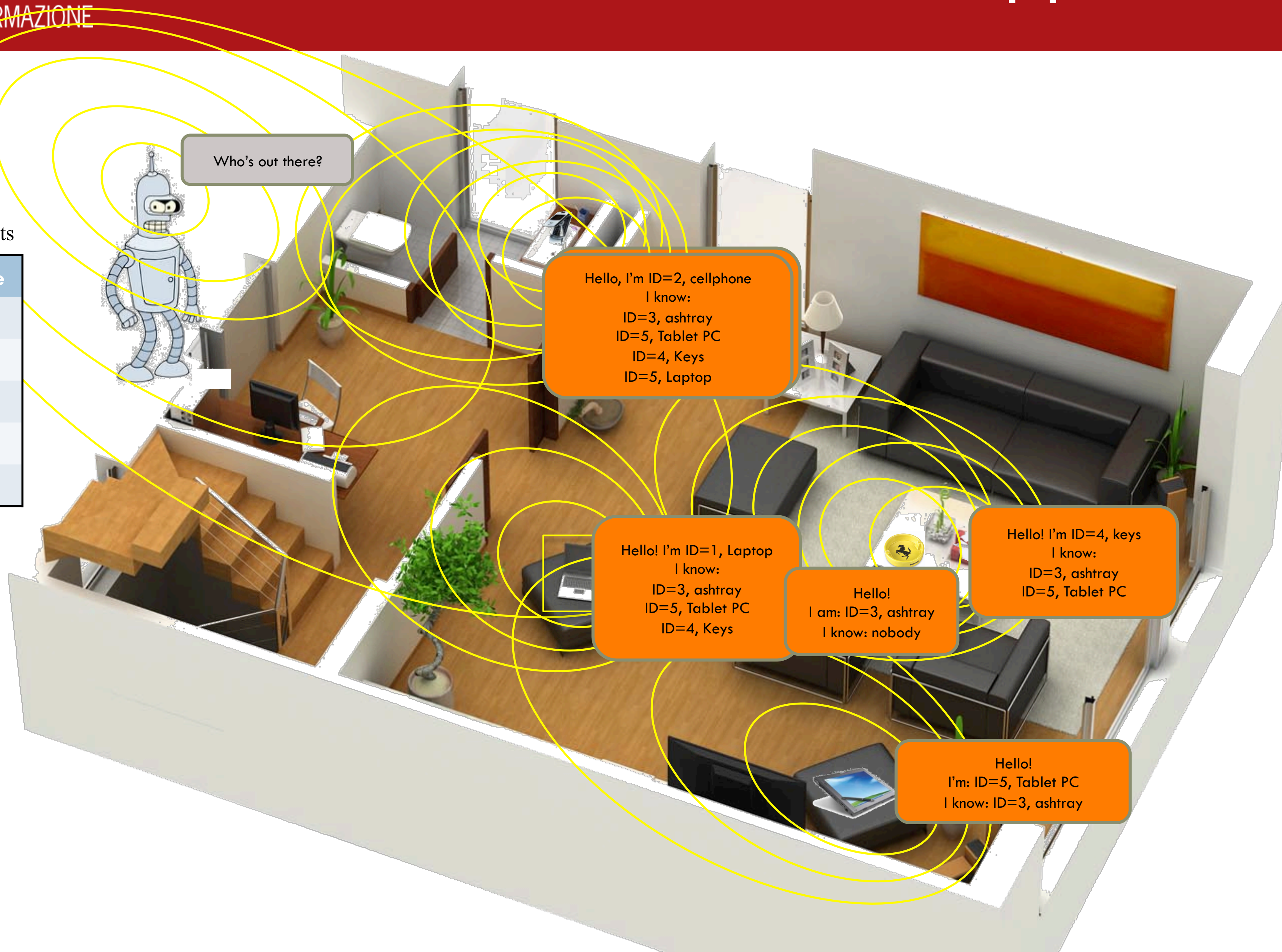
ID	Object type



Identification: distributed approach

Smart Objects Lists

ID	Object type
3	ashtray
5	Tablet PC
4	Keys
1	Laptop
2	Cell phone



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Step 2. Smart Objects Mapping

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Mapping: still a challenge

- GPS works pretty well… outdoor…
  - Not that well indoor though!
  - Hungry for energy (& money): not suitable for SOs
- Cricket-like systems work fine, but require dedicated hw
  - Impact on device size, cost, location, energy efficiency…
- RF-based localization techniques are very attractive…
  - if you're not too picky about performance!
    - Radio Signal Strength Indication (RSSI) is natively provided by all WSN platforms
    - However, RSSI-based ranging is usually VERY noisy!

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Mapping: our solution

WSN-wise

- Improve RSSI-based ranging by using the communication capabilities of WSNs
  - Multi-channel RSSI averaging

AMR-wise

- Use on-board odometers of the AMR and its computational capabilities to perform sophisticated localization algorithm
  - SLAM: Simultaneous Localization (of the AMR) And Mapping (of the SOs)

RSSI-based ranging: basics

- Path loss channel model
  - received power Pi @ distance d_i

environmental constant

transmitter-receiver distance

Shadowing

$$P_i\,[dBm] = \underbrace{P_{Tx} + K - 10\eta\log_{10}\left[\frac{d_i}{d_0}\right]}_{\text{Deterministic component}} + \underbrace{\Psi_i + \alpha_i(t)}_{\text{Random term}}$$

Received power

Transmit power

Path loss coefficient

reference distance

Fast Fading

Deterministic component

Random term

Propagation-based ranging

$$\hat{d}_i = 10^{\frac{P_{Tx}+K-P_i[dBm]}{10\eta}} = d_i 10^{-\frac{\psi_i}{10\eta}}$$

Ranging error

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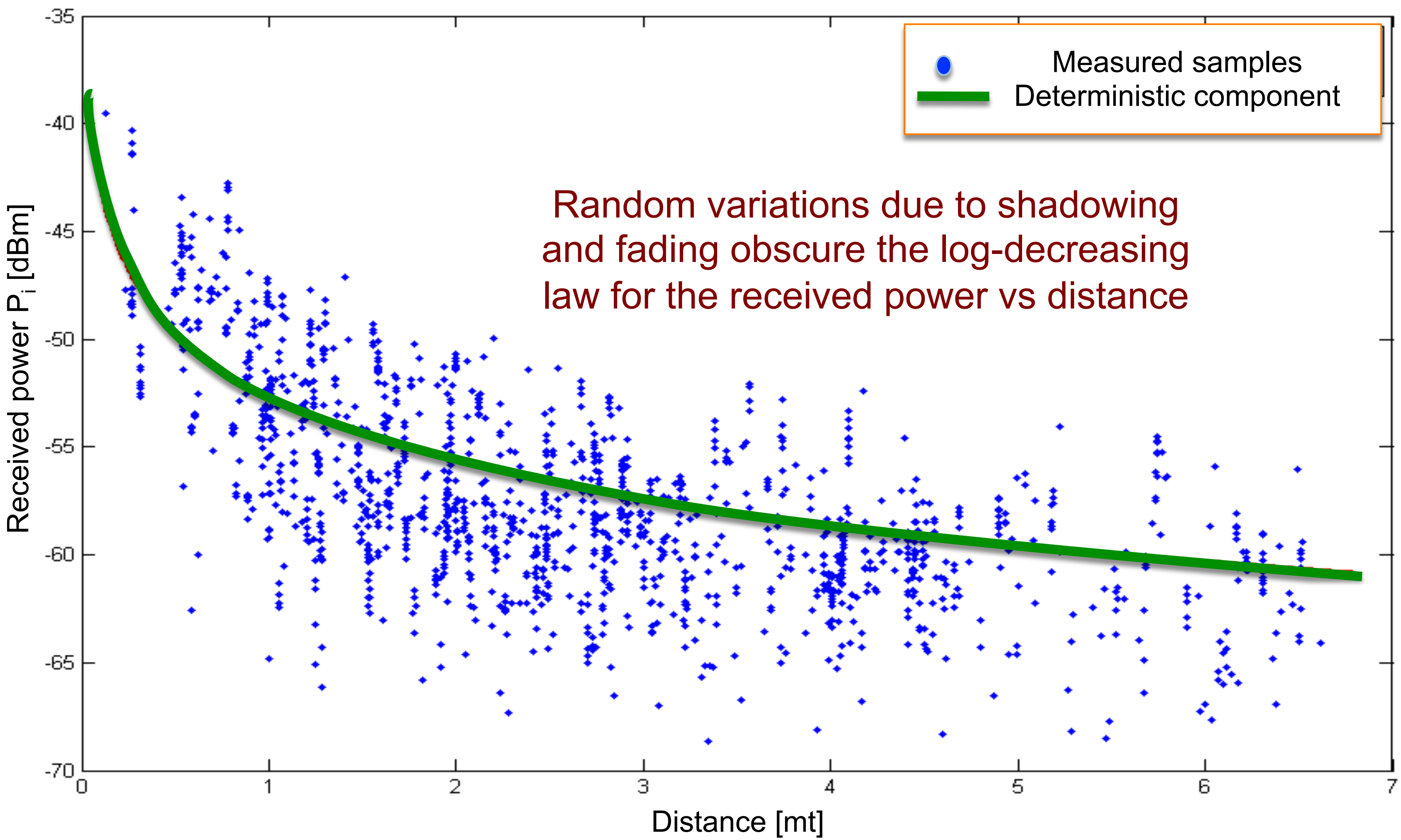
RSSI-ranging: an example...



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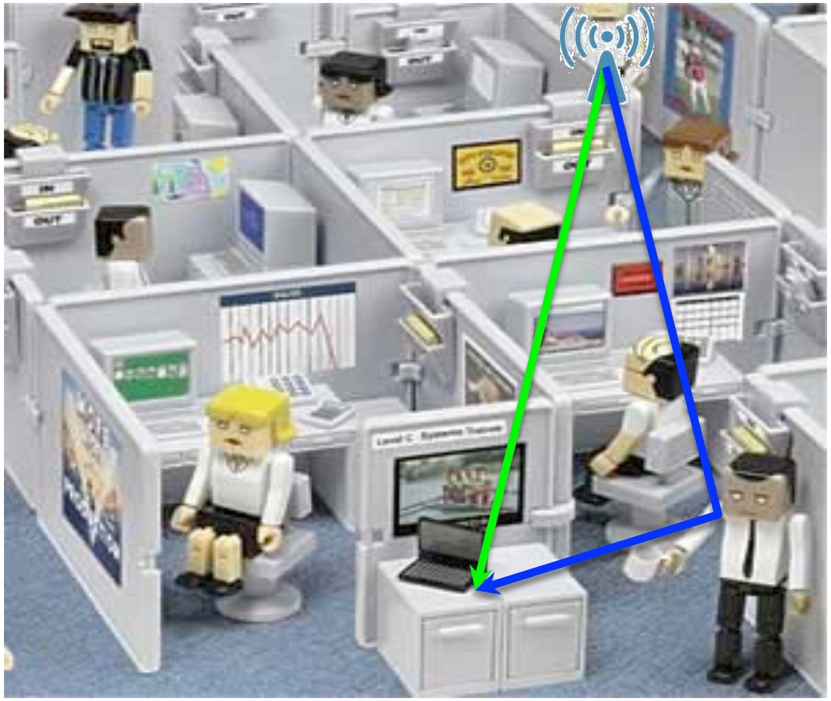
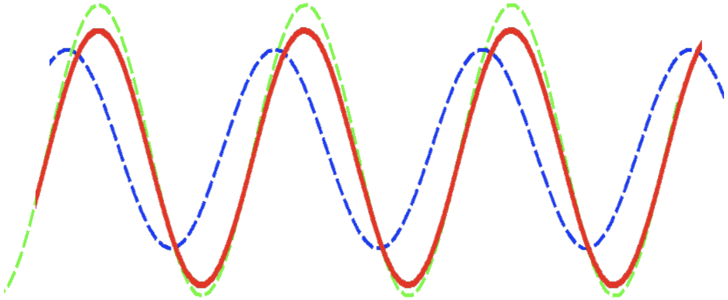
Mitigating RSSI randomness

- Shadowing term is actually due to strong and slowly time varying multipath interference
- A shift in the carrier frequency will change the way reflected copies combine at the receiver





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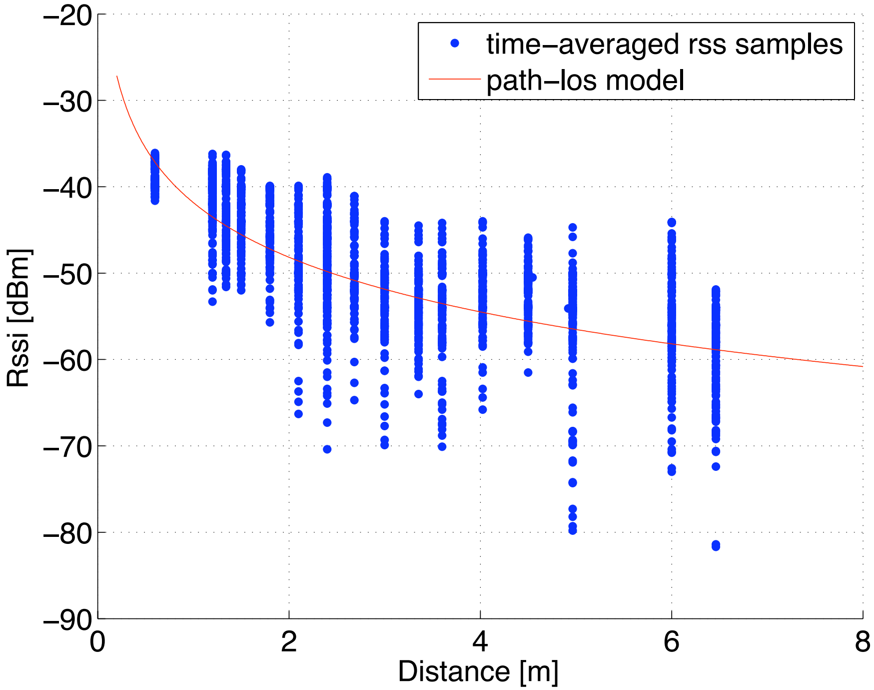
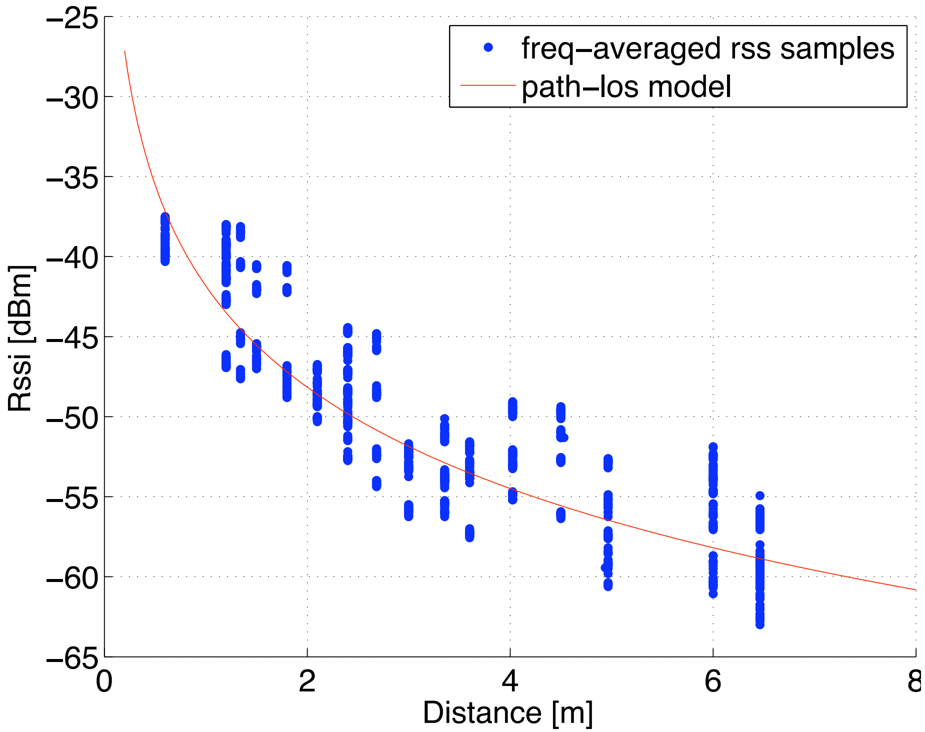
Multi-channel RSSI: experimental results

Time Average



Frequency average



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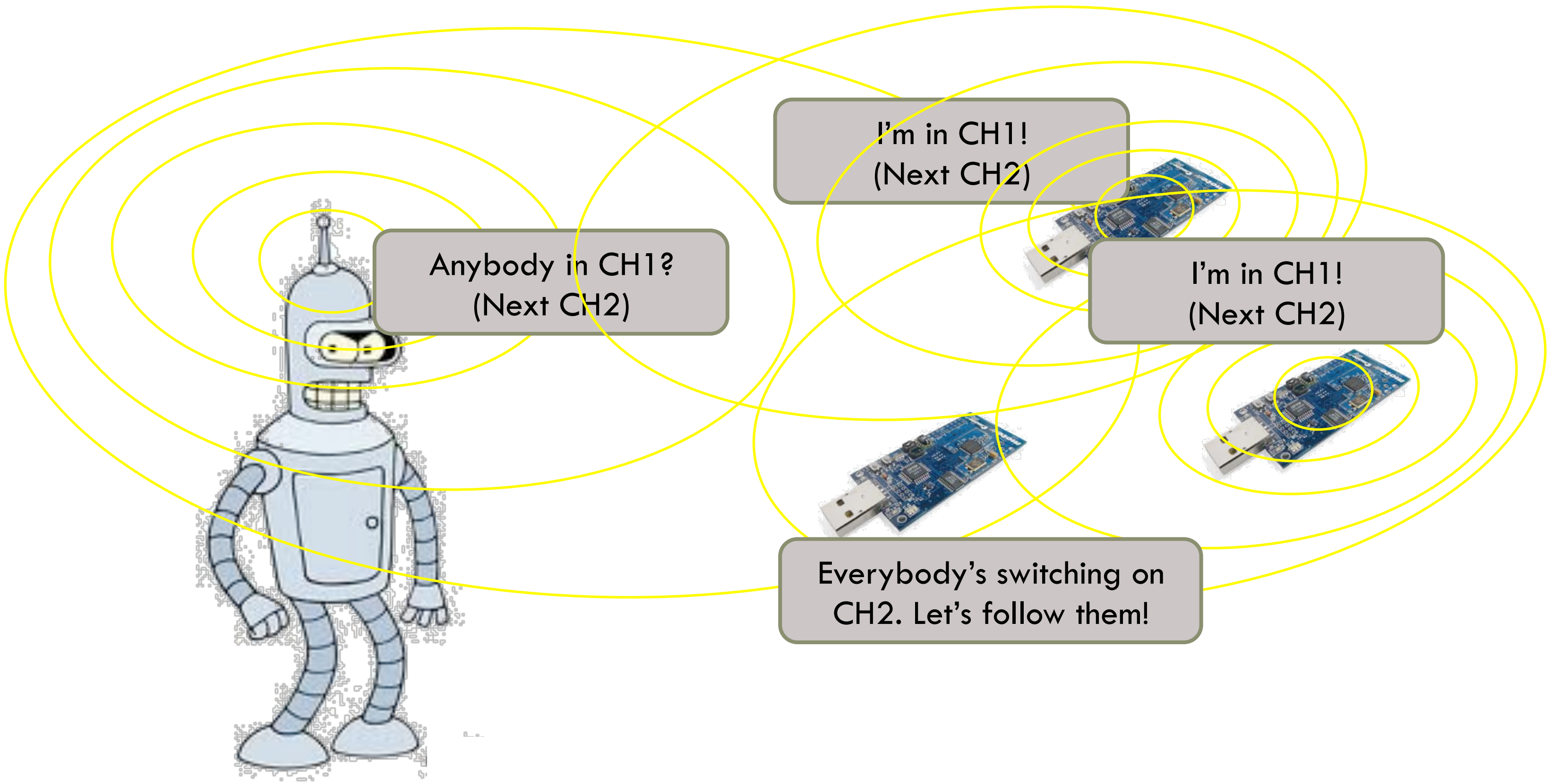
RF-jumping protocol in a nutshell!



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RF-jumping protocol

AMR side

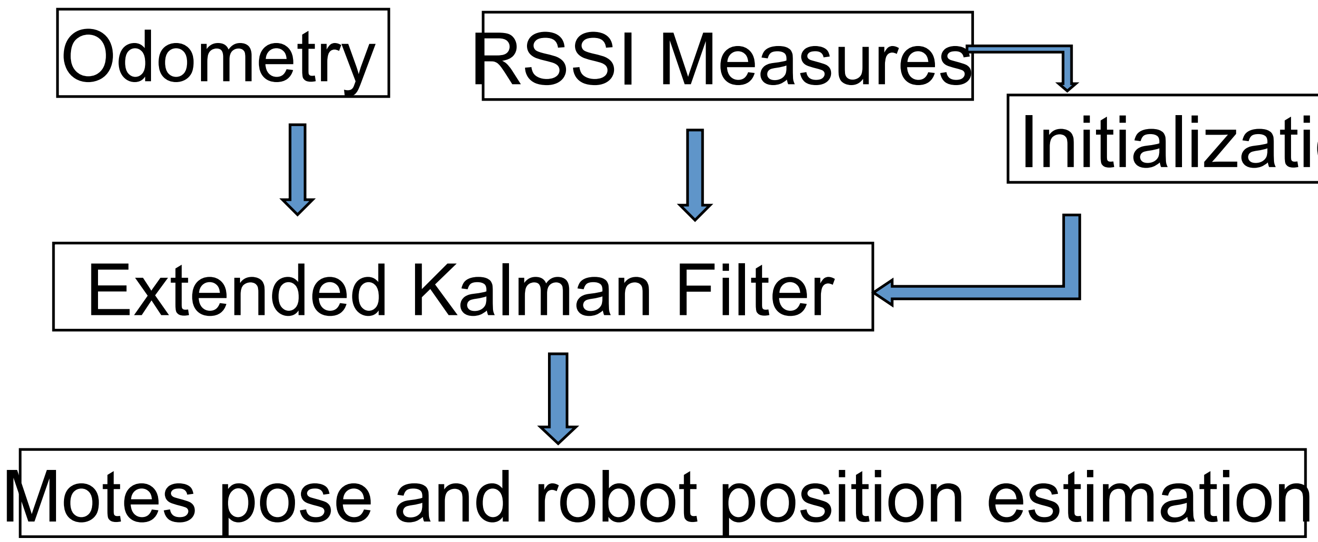
- Set TX Channel to default RF Channel
- FOR NextRFCh=1 TO 16 DO
  - Send REQUEST(NextRFCh)
    - Start REQ_TO
  - WHILE NOT(REQ_TO expired) DO
    - IF (REPLY pkt received)
      - Store RSSI sample
      - Restart REQ TimeOut
  - ENDWHILE
  - Set TX Channel to NextRFCh
- ENDFOR

SO side

- Set flag=false
- IF (REQUEST pkt received)
  - Get NextRFCh
  - Set flag=true
  - Set random REP_TO in [0,REQ_TO]
  - WHILE NOT(REP_TO expired) DO
    - IF (REPLY pkt received) & flag THEN Restart REP_TO
  - ENDWHILE
  - Send a REPLY pkt & switch to NextRFCh
- IF (REPLY pkt received) & NOT flag THEN
  - Get NextRFCh
  - Switch to NextRFCh

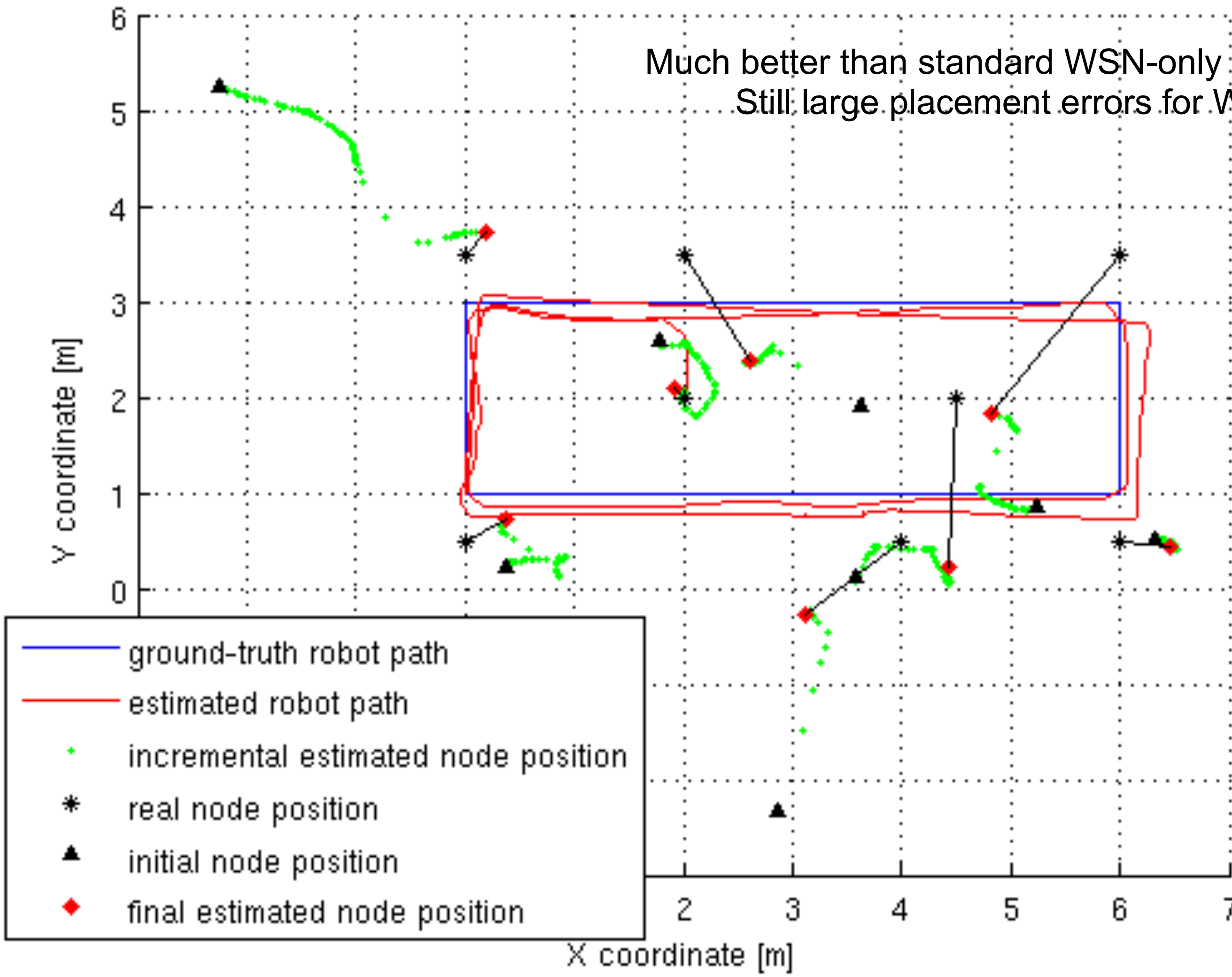
Standard SLAM

Localization Algorithm:



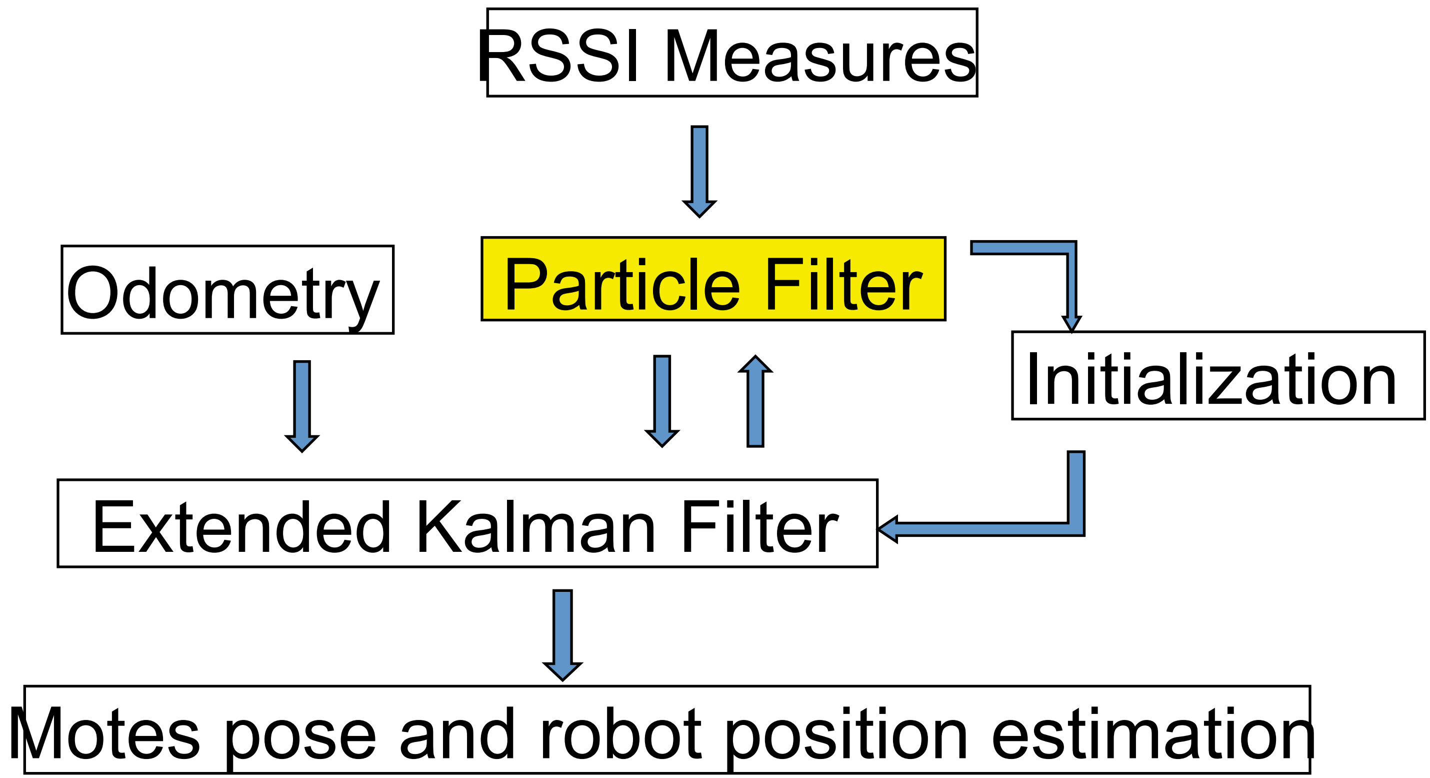
Standard SLAM result

Much better than standard WSN-only localization
Still large placement errors for WSNs



SLAM with particle filter

Localization Algorithm:



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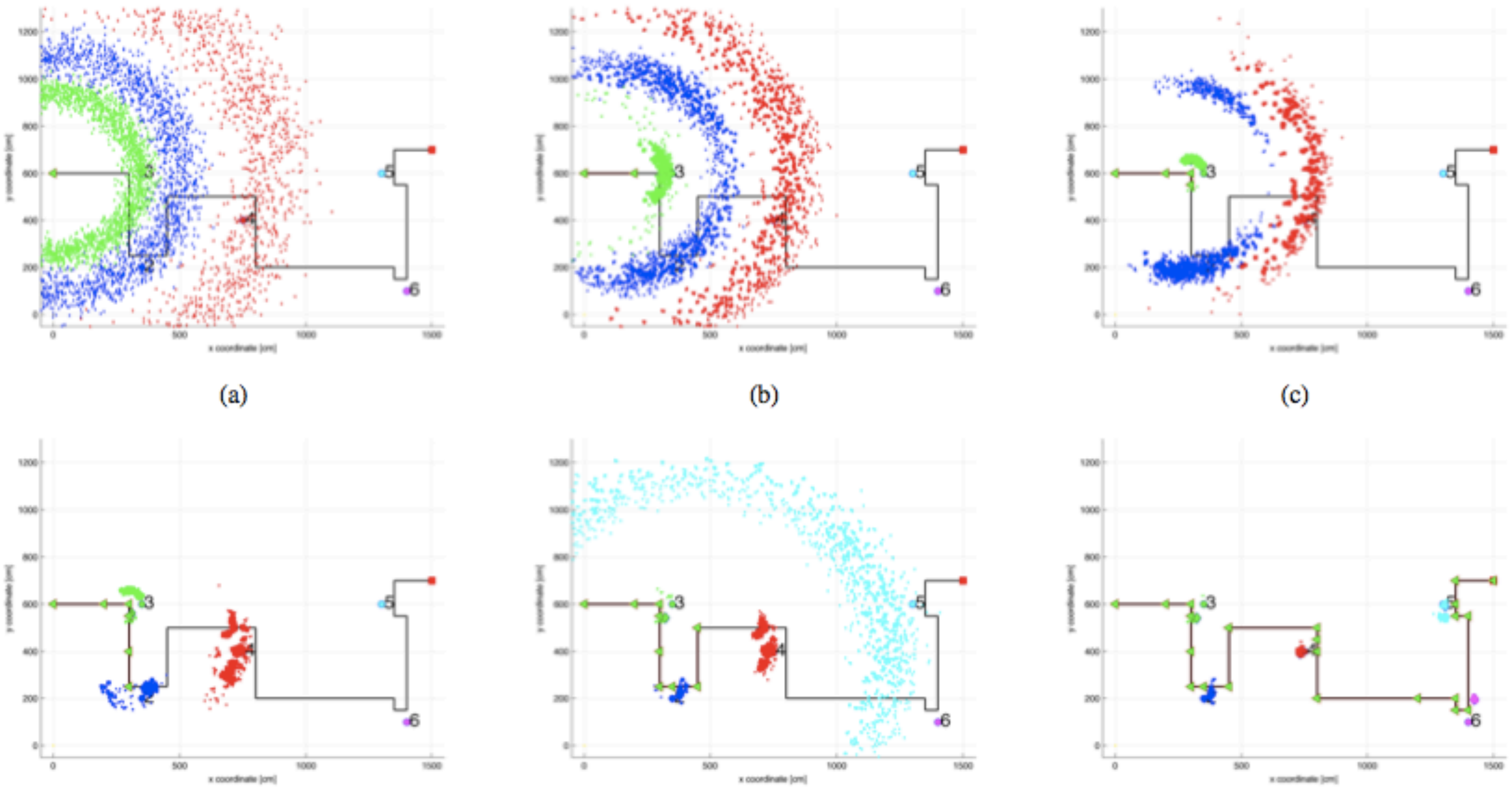
Delayed Initialization based on Particle Filter



(a) (b) (c)

(e) (f) (g)

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Step 3. Smart Objects Recognition

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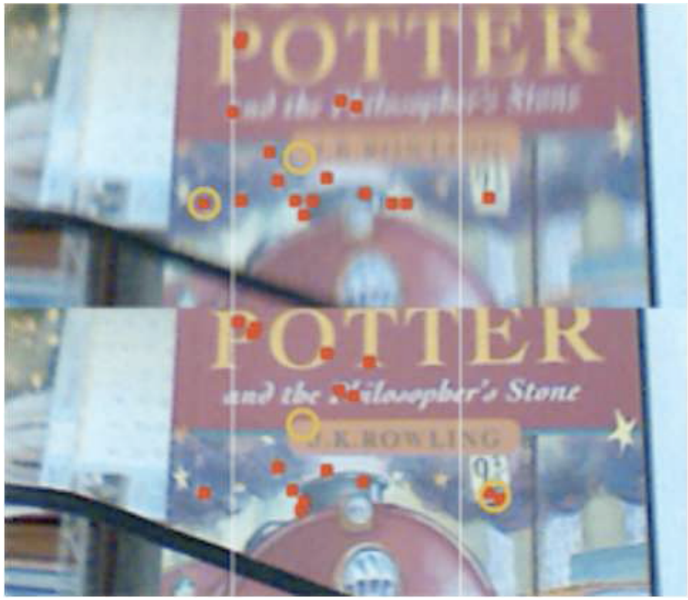
SO recognition by visual inspection

- The AMR should be able to recognize the objects from a description of the objects' appearance
- The object appearance is stored inside the object (in the motes)
- The appearance is coded by scale invariant feature descriptors robust also to motion blur (MoBIF)



Feature matching under motion blur (Pretto et al. ICRA 2009)

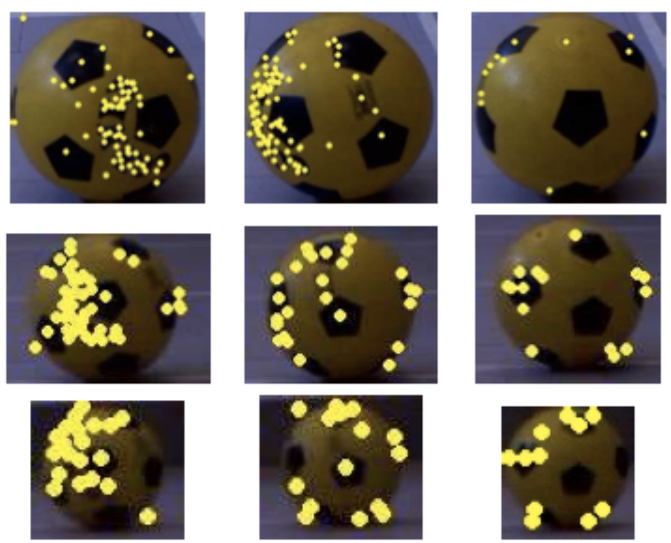
Storing the appearance

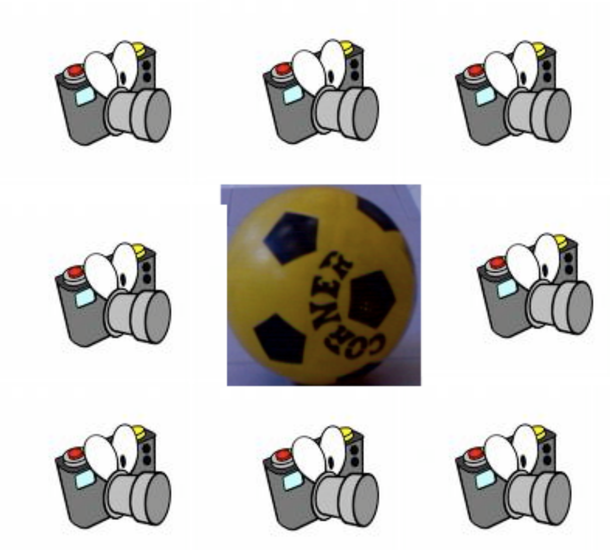
- Enhancing robustness to scale:
  - the object is imaged at different distances: near, medium, far
- Enhancing robustness to rotation:
  - the object is imaged every 20 deg.
- Limiting descriptors size
  - MoBIF descriptors extracted at different distances and angles are merged removing redundancy!

1 meter

2 meters

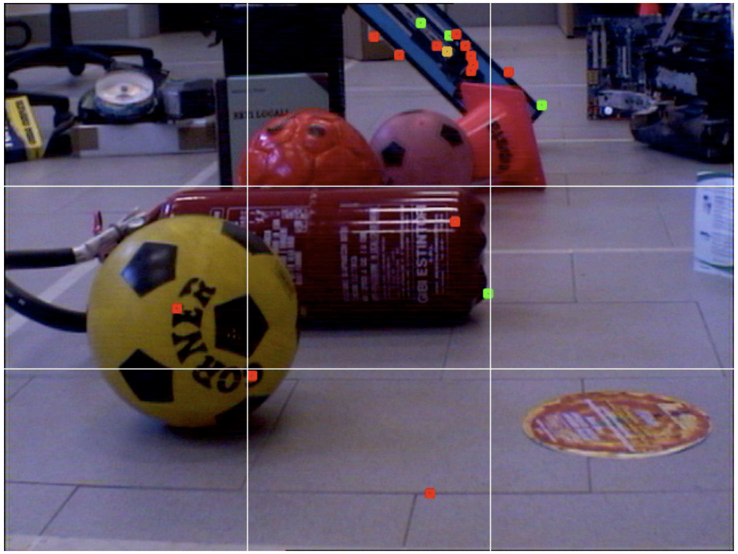
5 meters





MoBIF Matching

- The AMR requires the selected SO to send its MoBIF descriptors
- The AMR dynamically extracts MoBIF descriptor from the image taken by onboard camera
- When MoBIF descriptors matching exceeds a threshold the SO is recognized
  - matching is robust to scale, occlusion, illumination and rotation



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Conclusions

- Synergetic combination of WSN and AMR:
  - AMR helps WSN nodes localization
  - WSN helps object recognition and handling by AMRs
  - AMR & WSN together delivers new services
- Future work:
  - Improve localization by using also images taken by onboard camera into the SLAM algorithm
  - Include smart navigation algorithms to the framework
  - Adding object-handling algorithms to the system

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bibliography

- E. Menegatti, M. Danieletto, M. Mina, A. Pretto, A. Bardella, S. Zanconato, P. Zanuttigh, and A. Zanella, "Autonomous discovery, localization and recognition of smart objects through WSN and image features" in the proceedings of the IEEE Globecom 2010 Workshop on Towards SmArt COmmunications and Network technologies applied on Autonomous Systems, 6 december 2010, Miami, Florida, USA.

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Context-awareness and reactiveness

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Cognition-based Network

- Each node of the network:
  - exploits local information to achieve its goal
  - shares it with its neighbors

- Self-adaptation to the environment to achieve network wide goals
- Cognition applied to the entire network (not just at the PHY and MAC layers)

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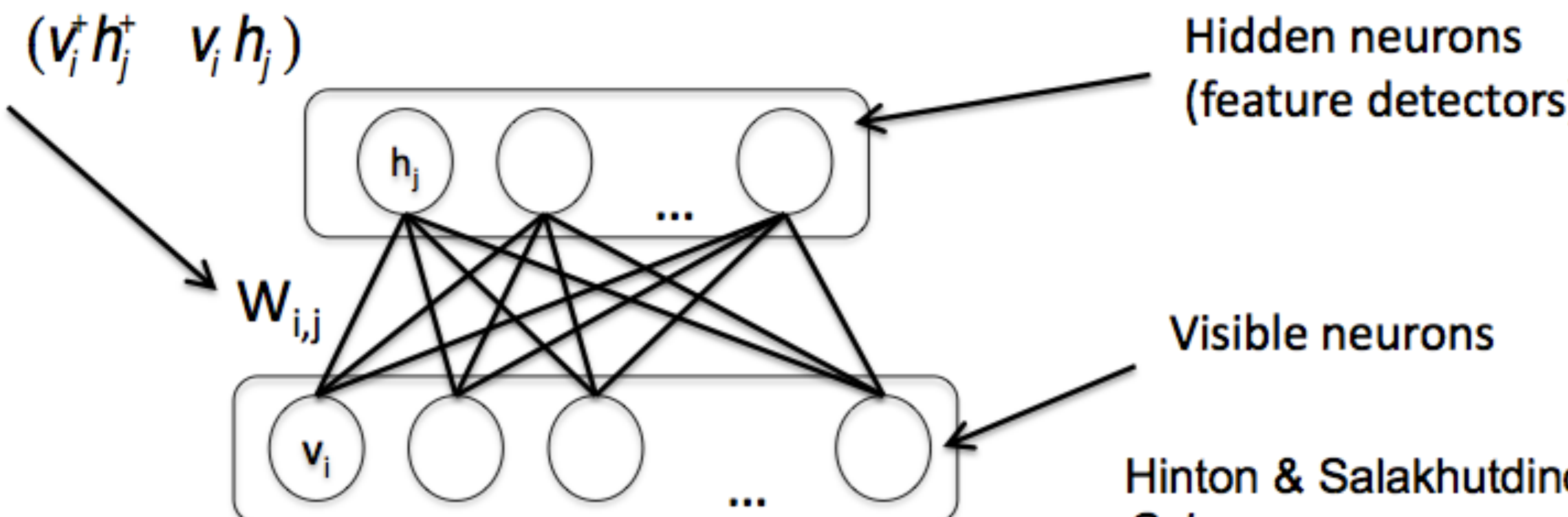
Restricted Boltzmann Machines (RBM)

- Stochastic neural network
  - input layer symmetrically connected with a hidden layer of feature-detectors
- Unsupervised learning of an internal model of the data

$$W_{i,j} = (v_i^+ h_j^+ \quad v_i h_j)$$



Hinton & Salakhutdinov, 2006, *Science*

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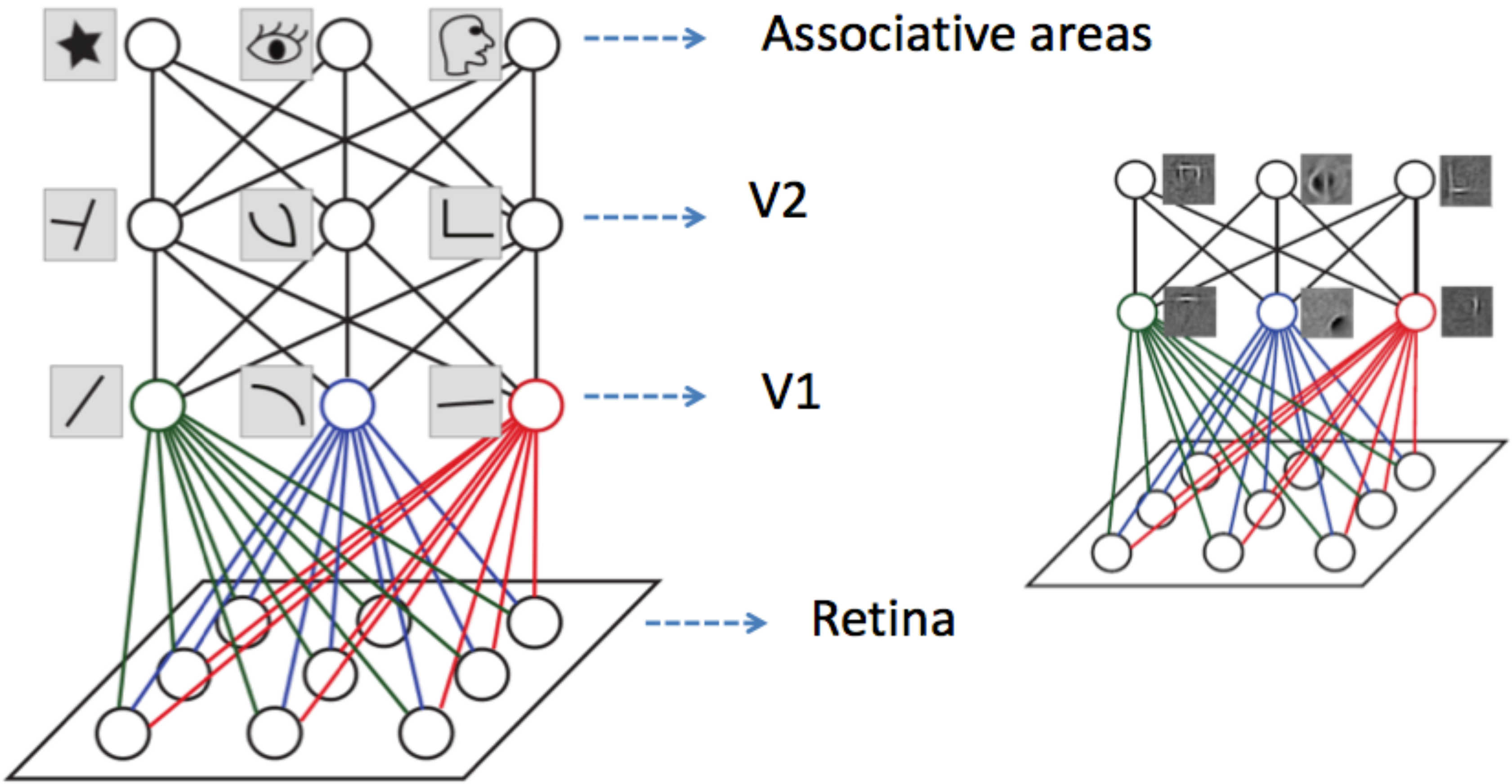
Hierarchical processing

A key feature of cortical computation



Example of learning/generation

Large scale simulation
Deep network 9 layers (1 billion connections)
10 million (200x200) unlabeled images

(Le et al., 2012)

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Example of applications

- Content-based video management
- Context-dependent handover in HetNets
- Context-aware proactive content caching
- …

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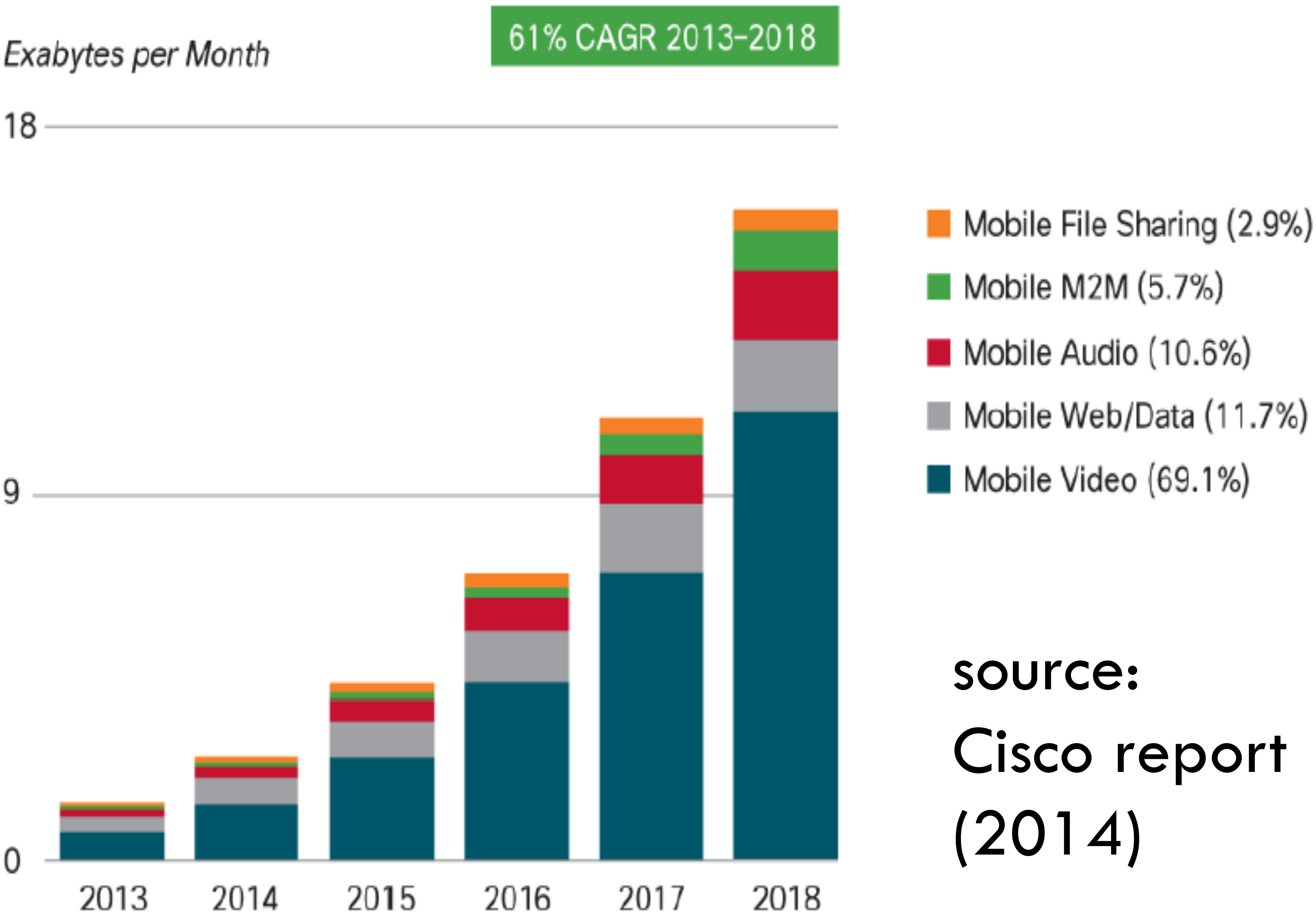
Multimedia growth



source:
Cisco report
(2014)

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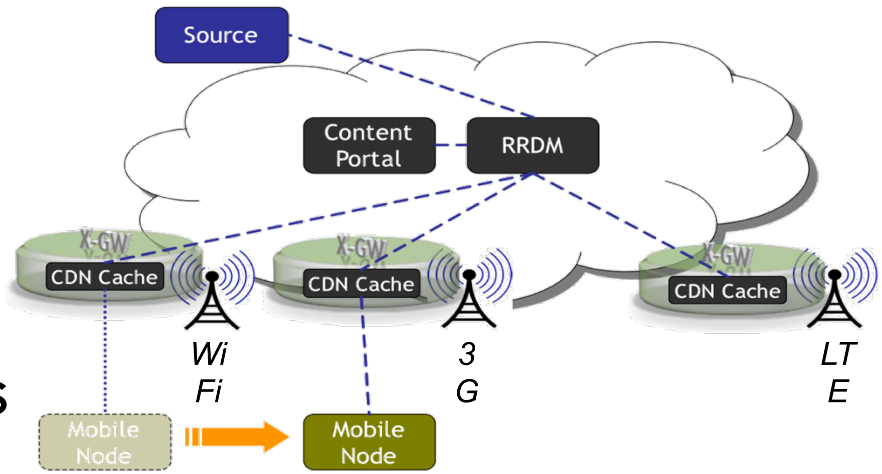
Challenges for video systems



- Heavy data
- Hierarchical system
- Backhaul network capacity
- Must handle different access techniques
- Needs to account for video popularity, heterogeneous user terminals
- Quality-of-Experience of video is hard to capture

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Analysis

- We consider a test set of 38 video clips, all encoded in an H.264-AVC format
- All the videos are encoded with a 16-frame structure (1 I-frame, 15 P-frames) and compressed with 18 different rates
- Depending on the content, the perceived quality of a compressed version changes
  - We used the SSIM indicator to capture it

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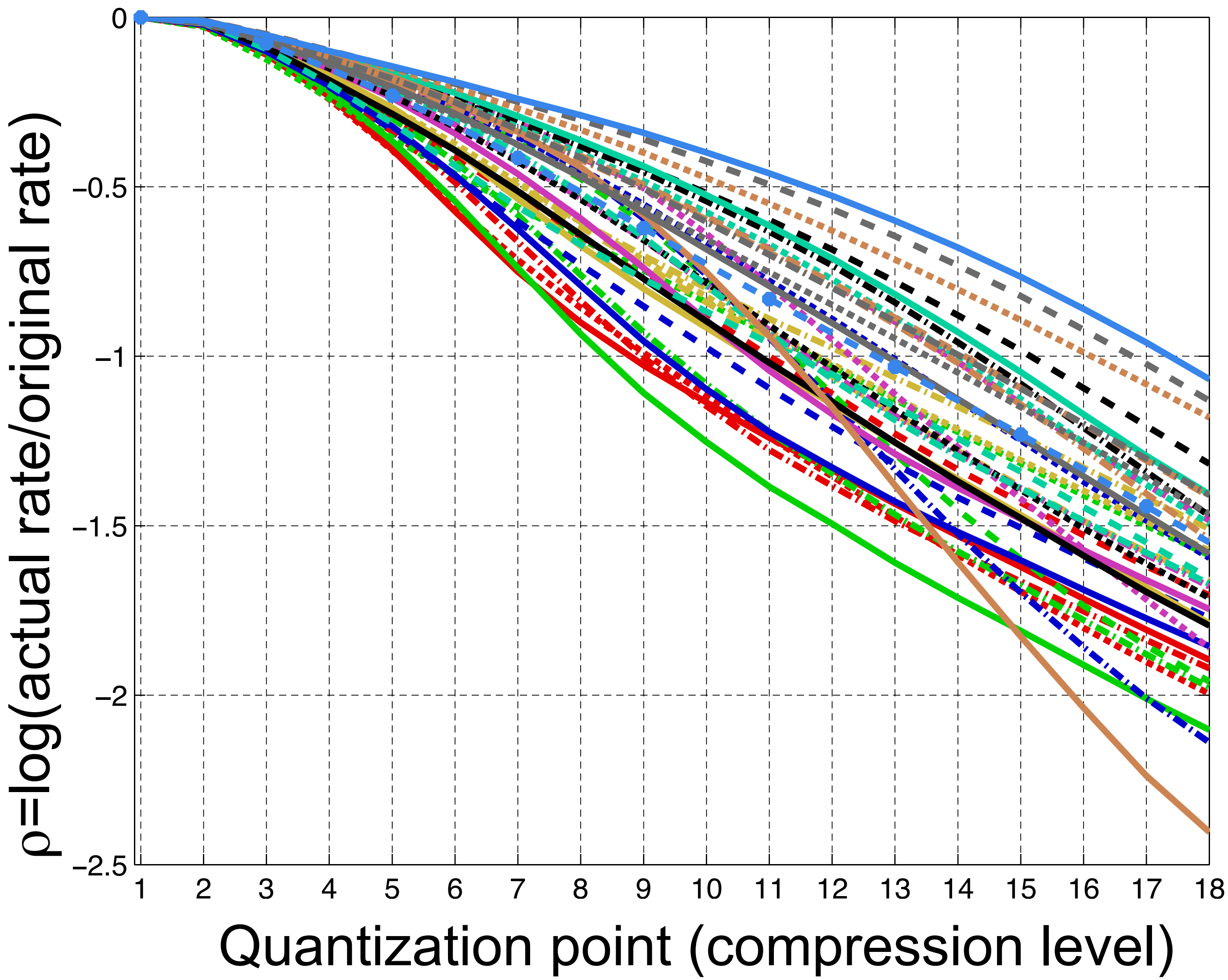
Rate versus compression



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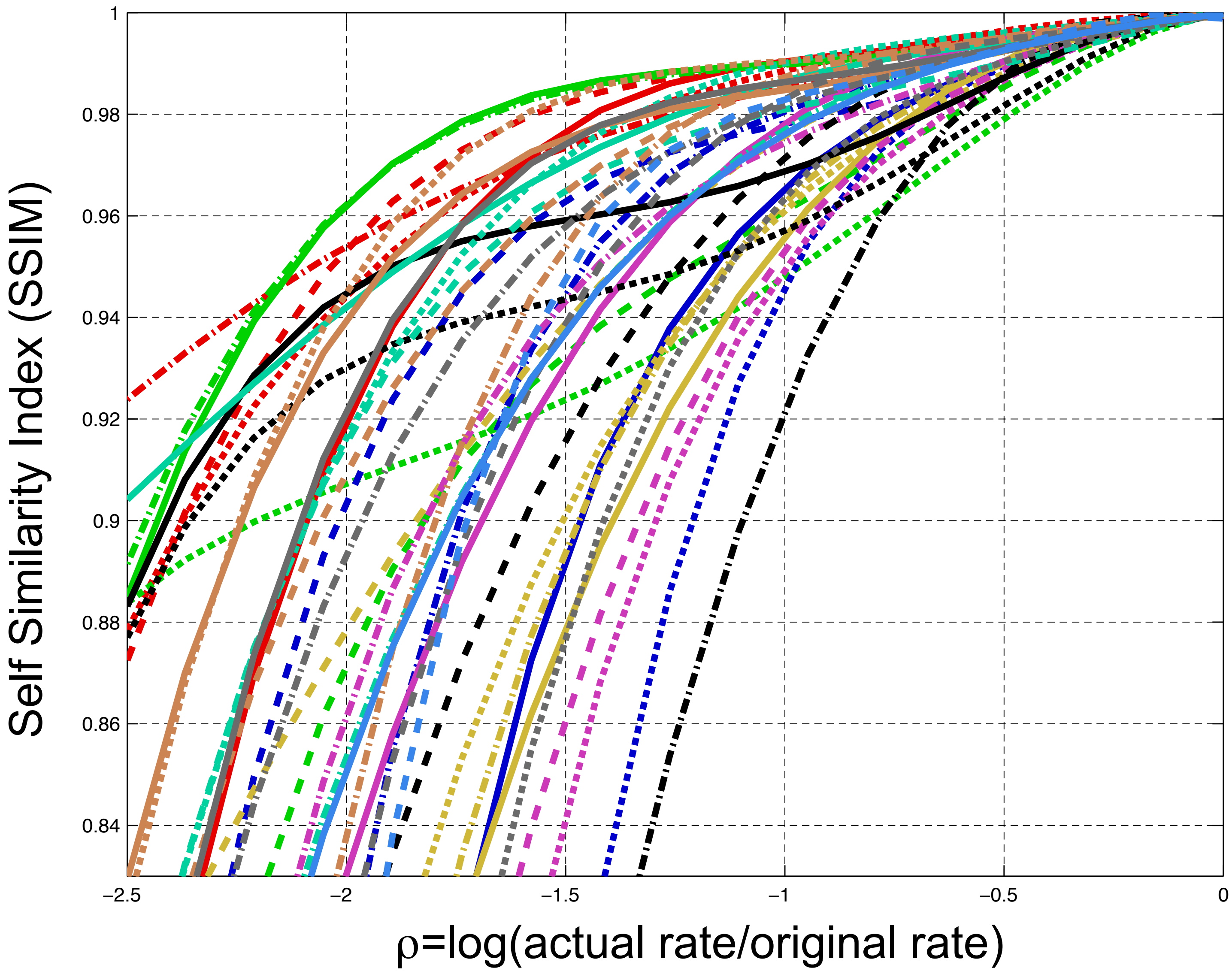
SSIM versus rate



Remarks

- All the video exhibit similar trends
  - monotonic descent
  - a steep "fall" after a threshold
- However, quantitative differences mean
  - different perceived end quality
  - different resource requirements
- These characteristics are more or less consistent within the same video

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Requirements for video delivery

- QoE-based and content-aware resource allocation
  - Rate-distortion curve depends on video content
  - Video content affects size of the encoded video frames
  - RBM can be used to infer rate-distortion curve of a video by observing the **size** (not the content) of video frames

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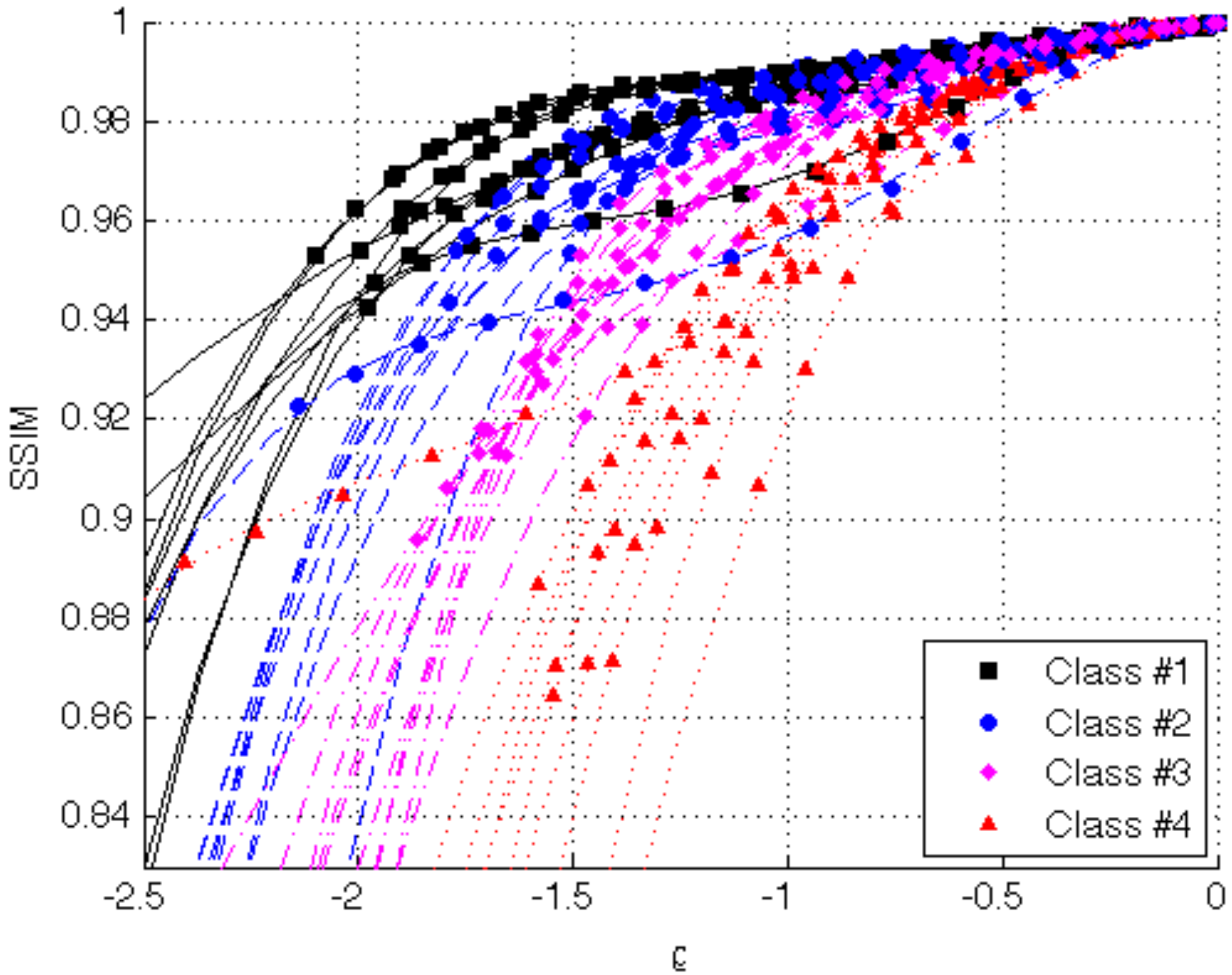
"Our" Video Classes



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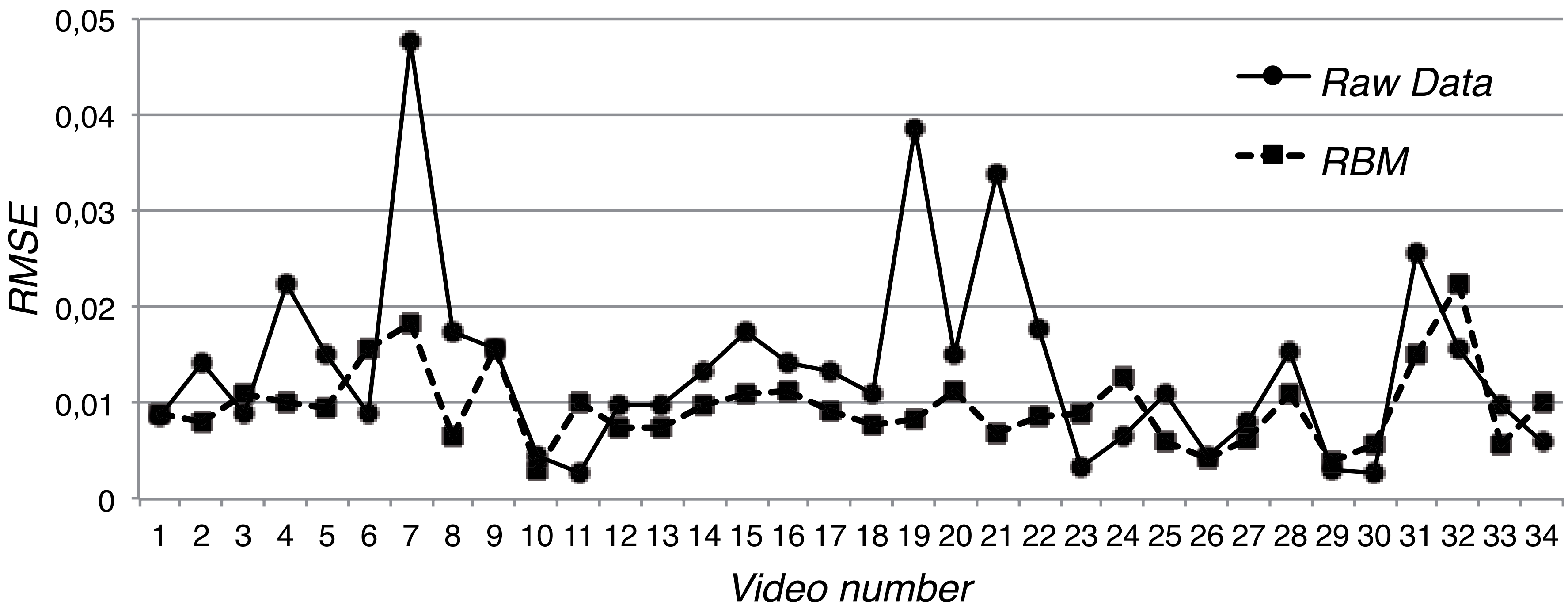
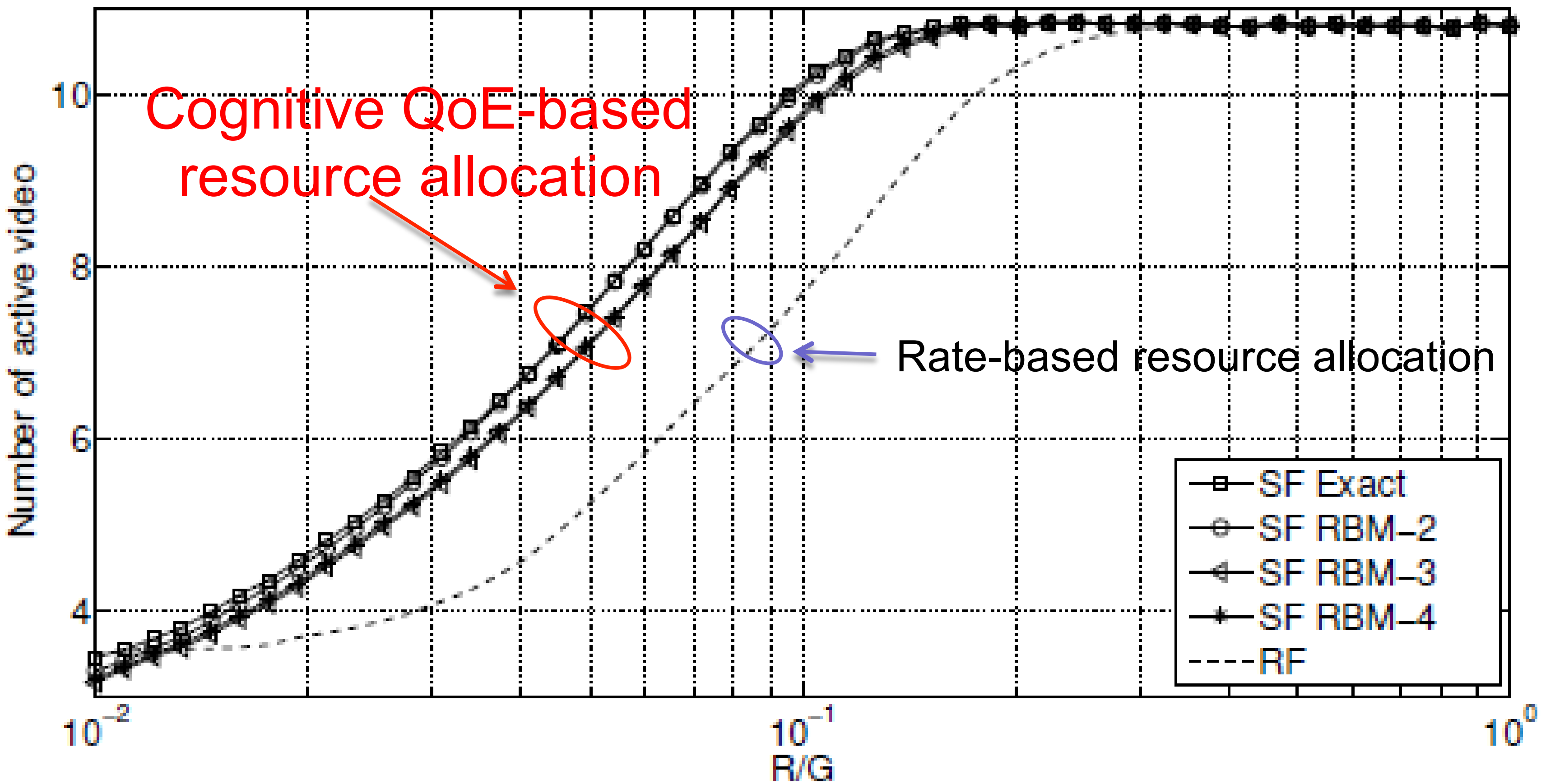
RBM SSIM estimate



Cognitive video admission control



Link rate over aggregate full-quality video rate

Conclusions

- need for consolidated understanding of the fundamental limits for
  - massive access
  - short packets
  - extremely variable transmission patterns
- Need for developing cognitive optimization modules that seamlessly interoperate at system level

That's all folks!