DESIGN, IMPLEMENTATION AND PERFORMANCE EVALUATION OF A PUBLISH-SUBSCRIBE ARCHITECTURE FOR INTERMITTENTLY CONNECTED 802.15.4 NETWORKS

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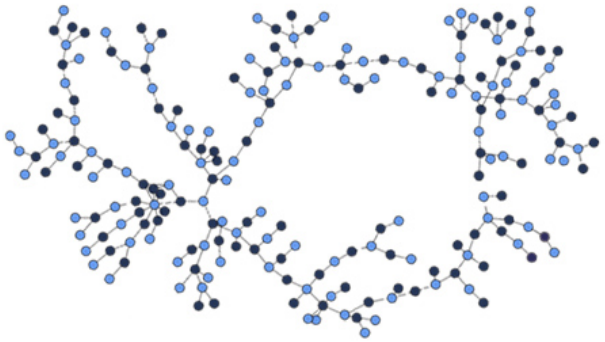
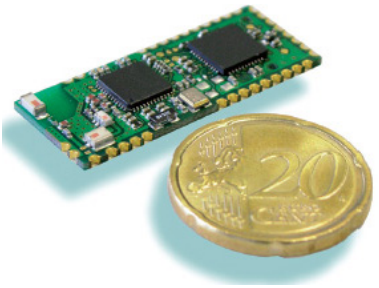


UNIVERSITA' degli STUDI di ROMA TOR VERGATA

TELECOM ITALIA

Technology: mobile terminals w/ IEEE 802.15.4

- Why IEEE 802.15.4 ?
  - Low energy consumpion against Bluetooth and WiFi
  - Very small size: embeddable (~5mm X 5mm)

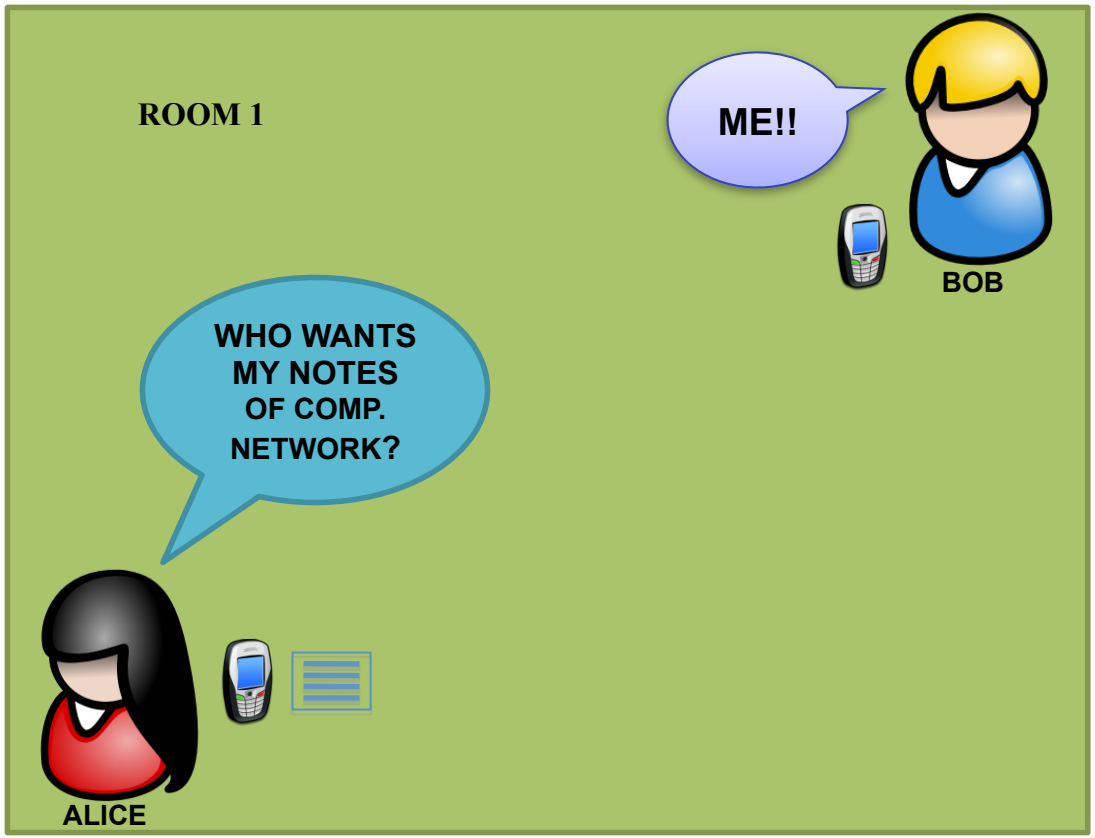


- Telecom Italia integrated SD and SIM card with IEEE 802.15.4/ZigBee devices
  - ZSIM and ZSD

- Very low resources (128**K**B Flash, 4/8KB Ram, 250Kbps max throughput, 1mW transmit power)

Why short range communications in proximity based services?

- Scenario: university campus



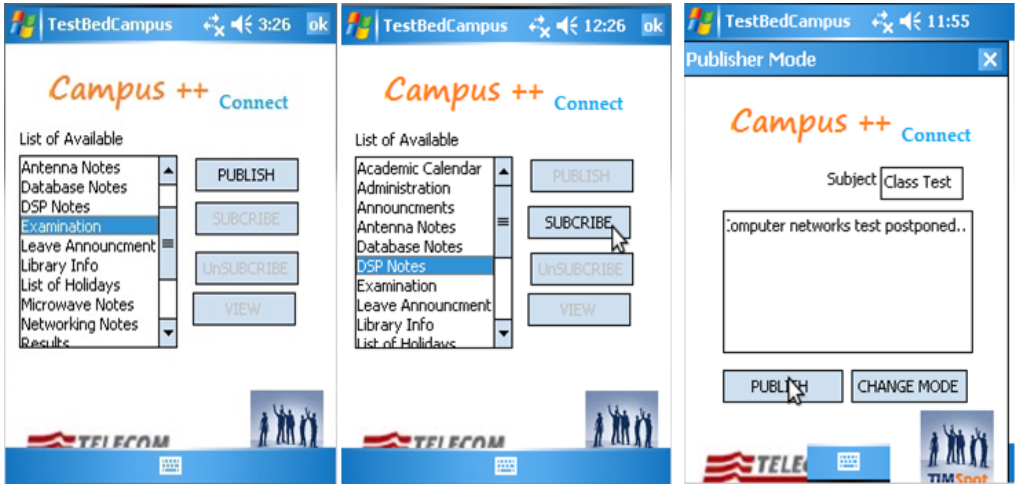
CAMPUS++: a topic-based pub/sub architecture for IEEE 802.15.4 DTN

- Intermittently connected networks → ***Delay Tolerant Networks (DTN)***
  - Support communications also between users directly connected to each other (store carry and forward)

- ***Topic-based publish/subscribe***
  - Users interested of a topic subscribe it
  - A data sample published on a given topic will be delivered to the subscribers of that topic
  - Publishers and Subscribers are loosely coupled

CAMPUS++ service framework

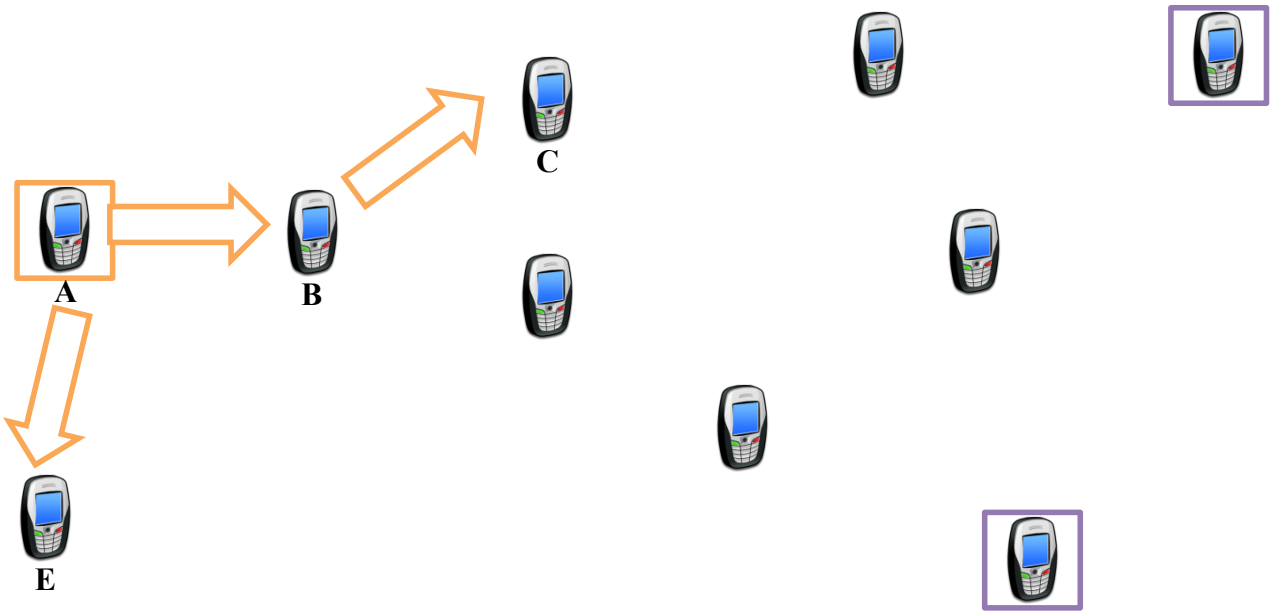
- ***Service framework***
  - User's PDA equipped with IEEE 802.15.4-capable SD cards
  - The Campus++ application allows to see the **topic** list which users can **subscribe**
  - Exchange of messages called "**Data Samples**" regarding specific topics
  - Once a topic is subscribed, data samples published of that topic are automatically received



Data sample delivery

- **Spray and Wait**[2] DTN routing scheme.
  - Data samples when published are replicated on **R** different nodes (including the source) that are the “carriers” of the data (SPRAY PHASE)
  - Wait untill one of the replicas reach the target(s) (WAIT PHASE)

R=4



[2] T. Spyropoulos, K. Psounis, C. S. Raghavendra, “***Efficient routing in intermittently connected mobile networks: the multiple-copy case IEEE/ACM Transactions on Networking”***, February 2008

Delay analysis

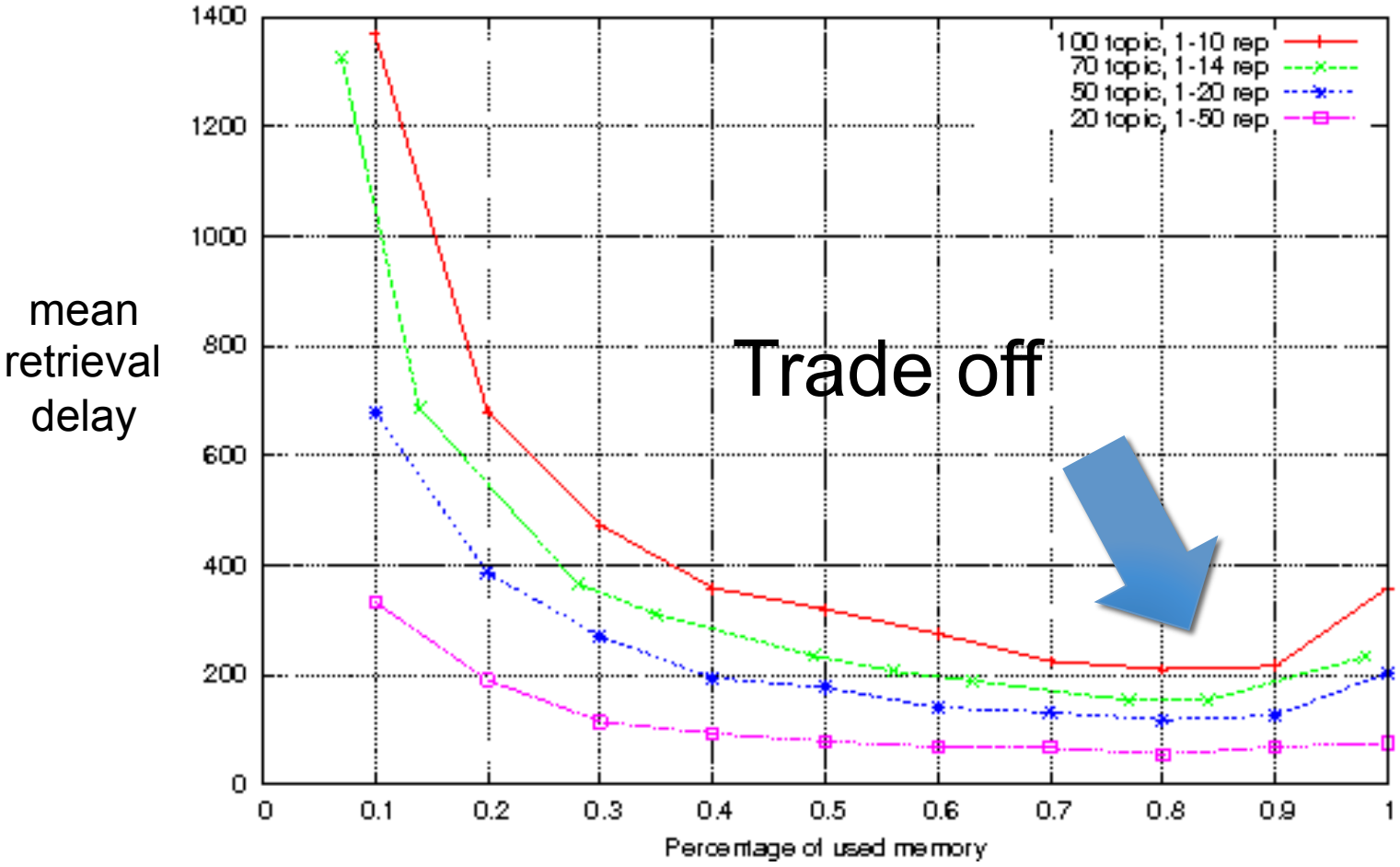
- The more the replicas in the system, the minor the average time to distribute a data-sample to all the subscribers
  - We call this time ***mean delivery delay***
  - …but we are *memory constrained*

- How to decide the right number of replicas “R”?
  1. Should we occupy 100% of the memory of the system?
  2. Should we advantage topics with a greater popularity (i.e. number of subscriptions) ?

- We resort to a two-step analysis and optimization:
  - First we analyze the system under the hypothesis of homogenous topic popularity,
  - After we consider different popularities

[1] mean time between the generation of a data-sample and the retrieval by a subscriber node

Several topics, same popularity: simulations



- The reason is due to the *Spray Time:* too much replicas decrease the probability to find other nodes with free memory space

Data sample delivery – Memory contraints

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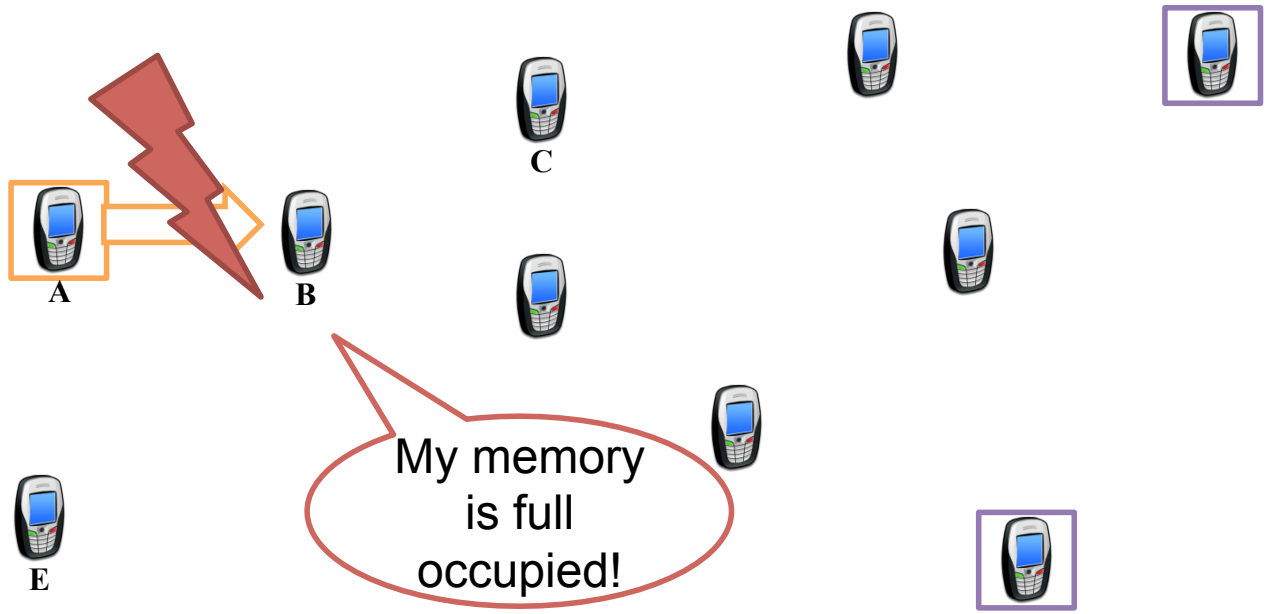

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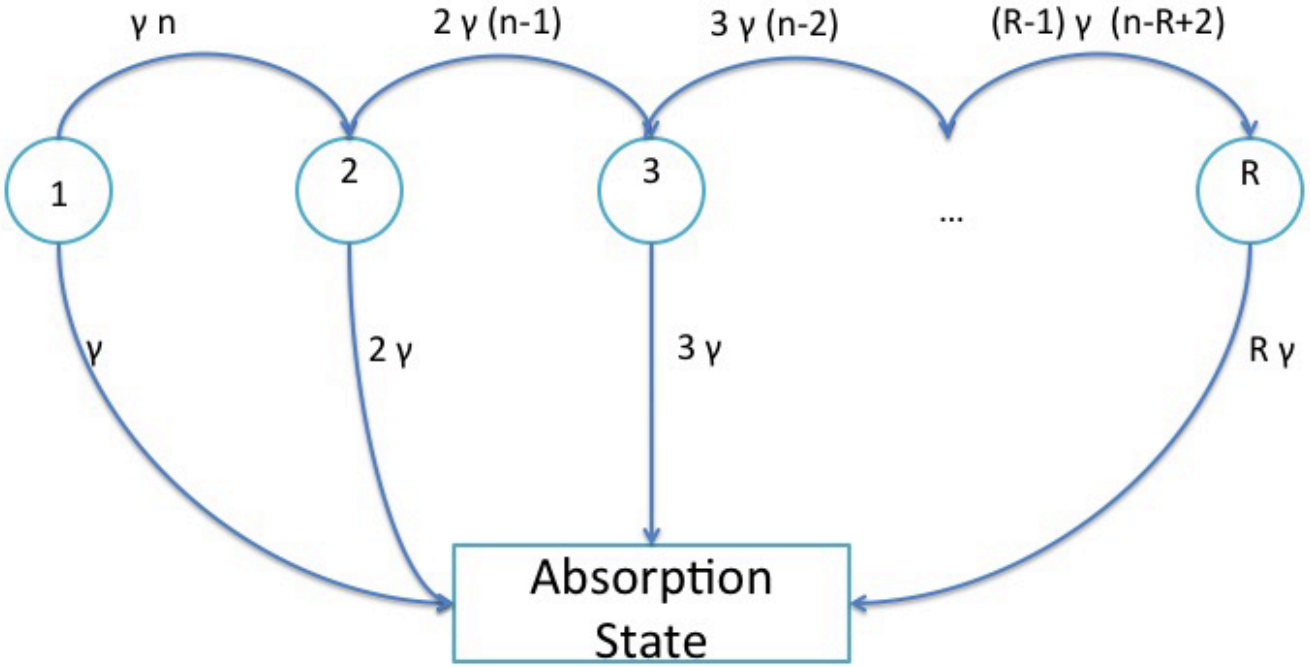
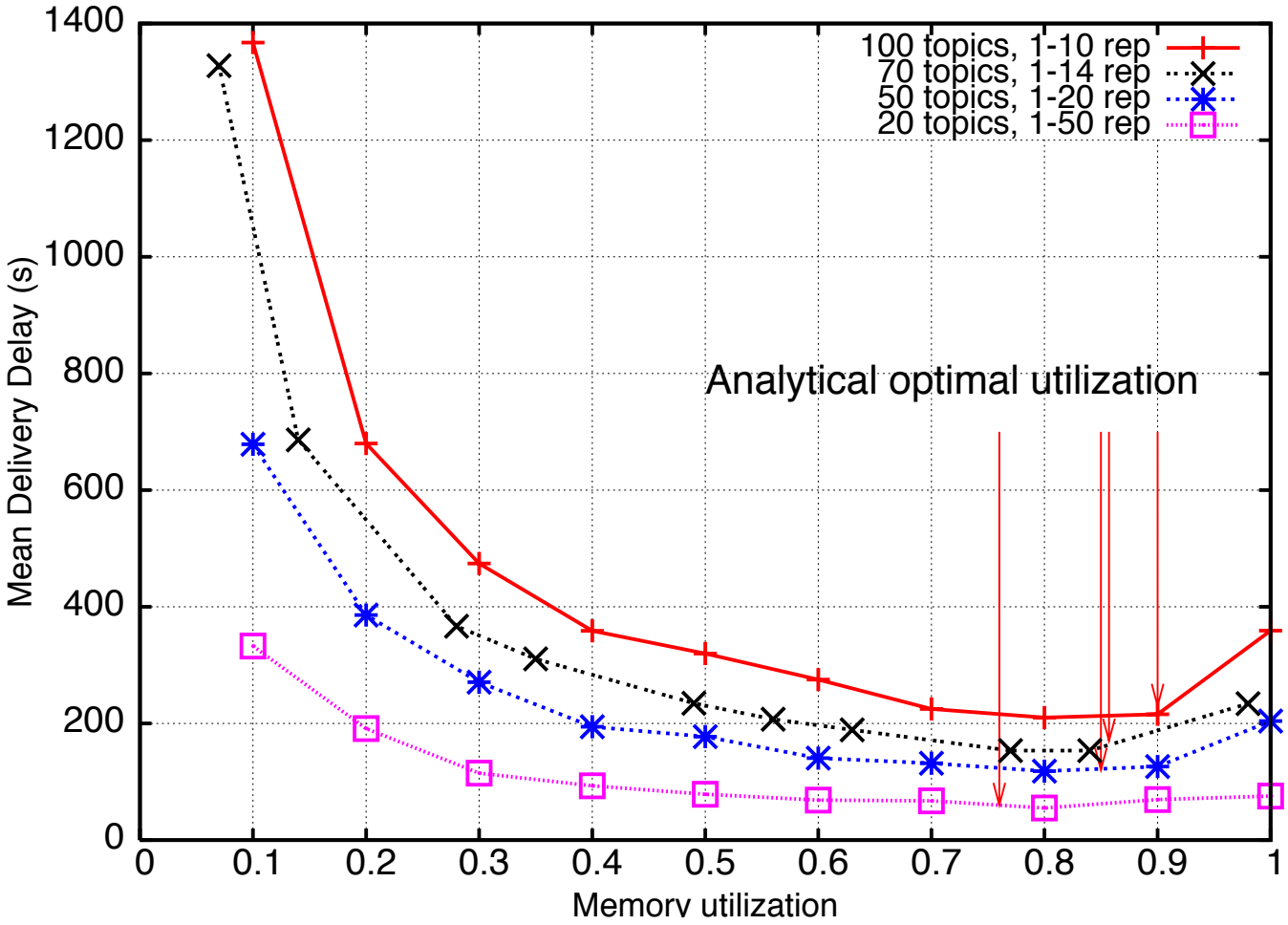
How to calculate the optimal memory utilization?

- R replicas (homogeneous)
- γ = Inter-meeting frequency
- n = Nodes in the system *with (at least) one free memory slot*



Delay: $$D = \frac{H_R - 1}{(n+1)\gamma} + \frac{1}{R}$$

Random Waypoint



Simulative approach with event driven simulator:

- 100 nodes
- Random Way Point mobility model on a 500x500 m^2 surface
- Coverage range 50 m

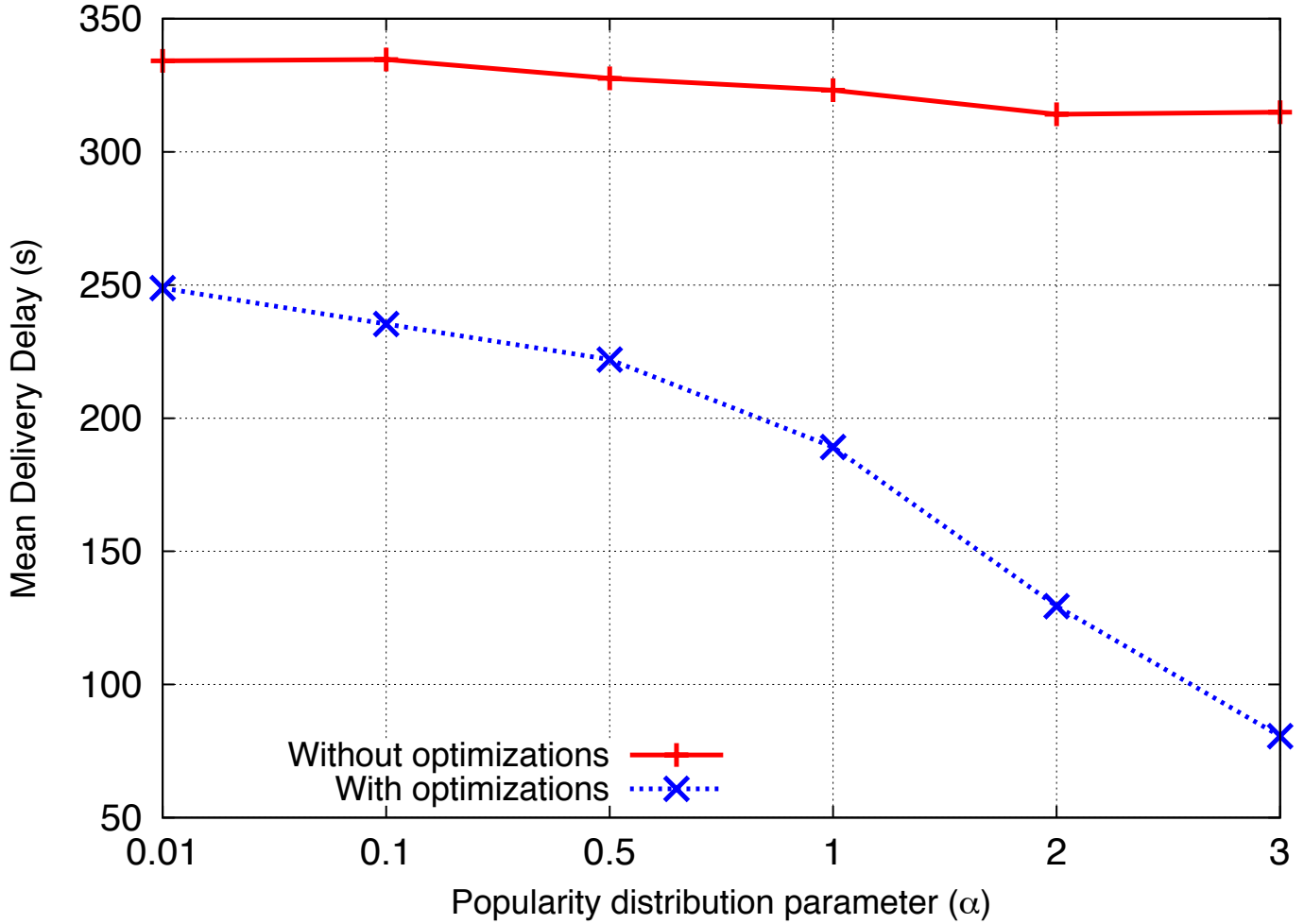
Introducing topic popularity

- The number of subscribers can be different for each topic (**topic popularity**): we can impose that subscribers of the popular topics see a minor delay than subscribers of unpopular topics
- Starting from the mean delivery delay of Spray and Wait and applying Lagrange optimization a model can be derived to find an optimal number of replicas for each topic

$$R_i = C_{tot} \frac{\sqrt{S_i}}{\sqrt{S_1 + \ldots \sqrt{S_T}}}$$

- R_i : number of replicas of i-th topic
- C_{tot} : memory capacity of the system (previously calculated)
- S_i : subscriptions for the i-th topic

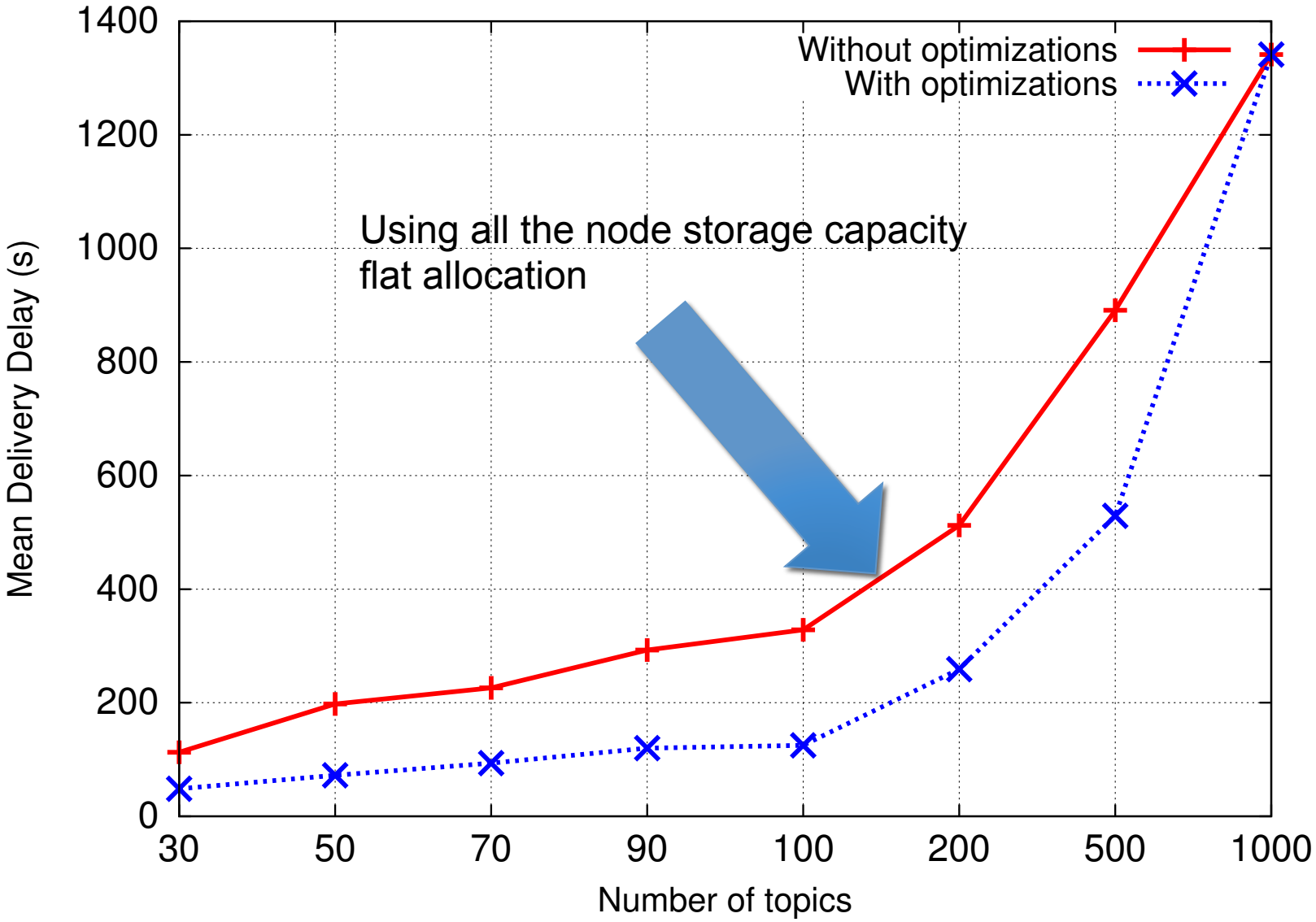
Popularity optimization



- Zipf popularity distribution with parameter α

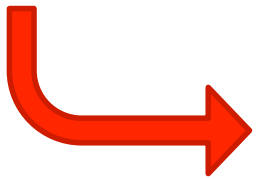
Optimizations effectiveness

zipf, α=1.8



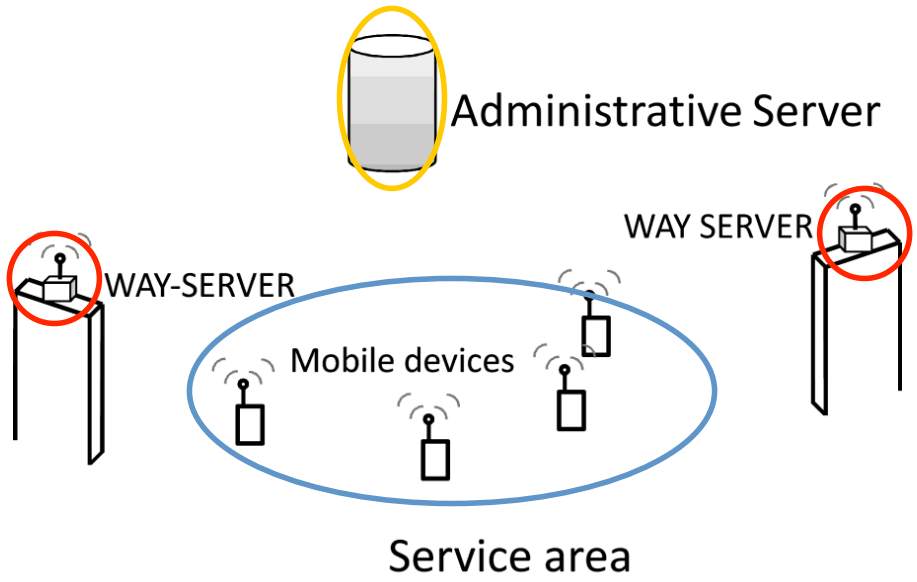
Key issues of the system

- **Replication Control**: R replicas of a data-sample have to share a distributed storage space. Tradeoff between mean delivery delay and storage space taking in account the popularity of different topics.
- **Data Obsolescence**: Oldest data sample have to be removed from the system when new data-samples are published. Newer and older data-samples have to be distinguished
- **Distribution of Control Data**: control information (e.g. Topic list, number of subscribers per topic, etc...) must be distributed to all nodes of the system
- **Ad-Hoc Mode**: the IEEE 802.15.4 standard does not provide any kind of ad-hoc mode. A PAN coordinator must be present to control the WPAN



System architecture, Application protocol

System Architecture



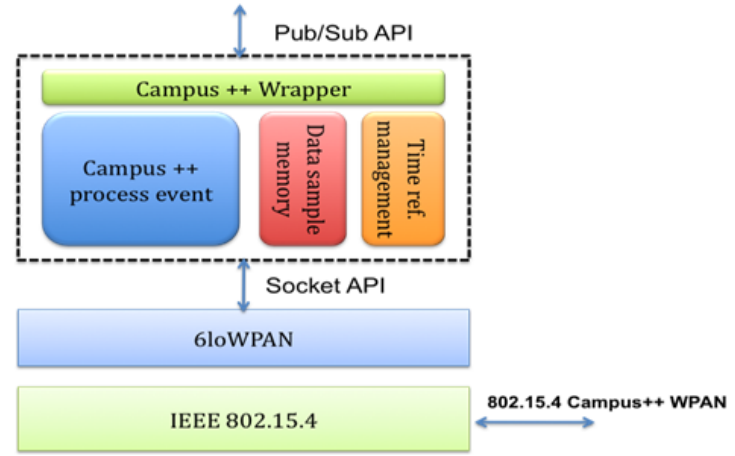
- Components:
  - **Mobile users devices**, publishers and subscribers of data-samples
  - **Way-servers**, publisher of control data (Built-in topic), provide user nodes with a loose clock reference, inform the Admin. Server about system parameters (number of users and subscriptions per-topic received)
  - **Admin. Server**, provides the way-servers the set of control data (topic list, overall system memory, clock reference)

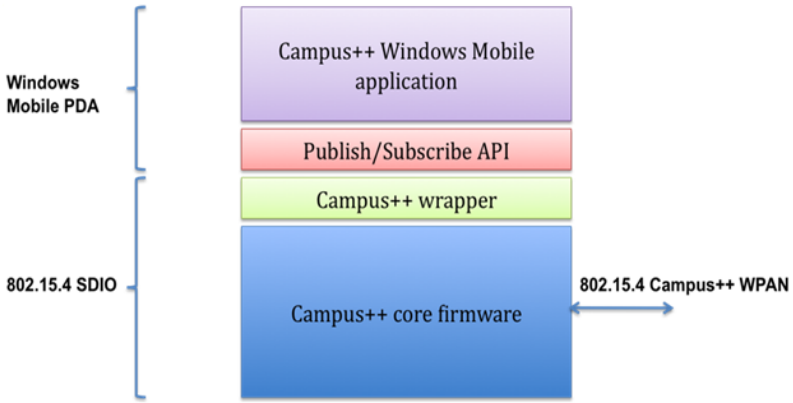
Control Data are distributed using a special topic called "**built-in topic**" published *only by Way-servers* and subscribed by *all user nodes*. The distribution of built-in topic data samples is **epidemic** (the number of copies to distribute is not fixed)

Data exchange: MAC and 6LoWPAN

- Direct communications between users: IEEE 802.15.4 + 6LoWPAN stack developed in our last project
- **Ad-hoc mode**:
  - Use of unique 64-bit extended MAC addresses of IEEE 802.15.4 devices
  - **Force all nodes to be PAN coordinator** (violation of 802.15.4 standard, but...)
- The hardware (TI CC2430) allows this mode of operations
- For security reasons PAN coordinators (all nodes) do not allow the association of other 802.15.4 nodes

Implementation





- All functionalities of Campus++ implemented in the firmware of CC2430 SoC
  - Code size ~ 60 KB
- Campus++ application developed on a Windows Mobile PDA
- The Campus++ mobile application interacts with the firmware by means of a publish/ subscribe API

Conclusions and Future Work

- IEEE 802.15.4 can be exploited for delivering location-based services

- Main contributions:
  - System design
  - Performance optimization
  - Implementation in a real testbed

- Future work
  - Future implementation: µSD + android terminals
  - Power consumptions measurements