Alma Mater Studiorum – University of Bologna
CdS Laurea Magistrale (MSc) in
Computer Science Engineering
II Term – Academic Year 2019/2020

Mobile Systems M (8 ECTS)

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`http://lia.disi.unibo.it/Courses/sm1920-info/`

`https://www.unibo.it/sitoweb/{paolo.bellavista, luca.foschini}`

Pre-requisites: **none**
But the contents of the "old" courses of computer networks (Reti di Calcolatori T and, even if partially, Infrastructures for Cloud Computing and Big Data M), Sistemi Operativi T, and Tecnologie Web T are **certainly useful**

Examination modes: long ☺ oral exam (with the possible discussion of a personal project – optional; also opportunity of Project Activity for 4 ECTS)

Course Goals (in extremely short): in-depth competence on models and solutions for **state-of-the-art mobile systems**, for **mobile services and applications** provisioned on top of them, and for the **support (middleware)** needed for the development and **runtime management** of them. Know-how about **methodologies, models, technologies, and implementations** to **design, implement, deploy, and runtime evaluate** mobile services

Output skills and abilities:

❑ ***Supplements of mobile communications and systems***

  ➢ introductory elements of propagation and fading models
  ➢ overview of primary characteristics of ***IEEE 802.11*** (infrastrucured, ad hoc – WiFiDirect - and mesh-oriented)
  ➢ overview of primary characteristics of ***cellular networking***
  ➢ overview of primary characteristics of ***IEEE 802.15***
  ➢ ***mobile ad hoc networks*** (MANET) and main related ***routing protocols***
  ➢ ***mobility management***, Mobile IP, iTCP, and positioning ***techniques***

❑ ***The mobile middleware concept***

  ➢ ***platform examples***, with in-depth technical presentation of Android features and programming model
  ➢ …

❑ ***The mobile middleware concept***
  - ➢ ***support technologies*** (SIP, edge cloud, 5G infrastructure, discovery in mobile environments, …)
  - ➢ advanced topics such as ***context awareness, service composition, and overlay networking***
  - ➢ ***publish/subscribe***
  - ➢ ***data synchronization***

❑ ***Application areas and domain-specific deployments***
  More «traditional» such as
  - ➢ location-aware and context-aware services
  - ➢ context management and smart spaces
  - …

❑ *Application areas and domain-specific deployments*

Or more «visionary» such as

➢ vehicular and/or high-mobility networks, Delay Tolerant Networking, opportunistic networking

➢ efficient integration mobile-to-cloud, cloudlet, fog computing, edge computing, virtualization and «containerization»

➢ *quality of information and sensed data in Internet-of-Things*, Value of   Information

➢ *edge/fog computing for Industry4.0* manufacturing production lines, predictive/proactive maintenance, federated machine learning, ...

➢ cooperative autonomous driving (fleet-oriented)

➢ …

In addition, the course will include:

❑ a few *guided lab exercises* about some topics and technologies described during lectures (horizontal and vertical handoff, Android, location-dependent services and positioning, Internet of Things management, cloudlets, …). These exercises will be solved autonomously by the students, with the support and supervision of the teacher; they will exploit advanced simulation environments (e.g., ns-2/ns-3, Qualnet, and SUMO) and Android/Raspberry PI devices

❑ discussion of *real/realistic case studies*, in particular in the application domains of *location/context-aware services, efficient IoT-edge-cloud integration, and edge-enabled industrial IoT*

❑ possible additional *seminars* to present significant *company case studies*

The exam will consist of:

❑ a ***LONG oral interview***, of course ☺ about the WHOLE technical programme of the course

❑ an optional discussion of ***a self-developed optional project*** (guided and negotiated with the teacher) on the design and implementation of middleware/applications that employ some technologies of primary interest for the course

The project, of course of ***greater complexity in the case*** ☺, can be <u>associated with a Project Activity (4 ECTS)</u>

<u>Exam dates</u> (8 dates per year will be fixed; additional dates will be available at <u>http://almaesami.unibo.it</u>, where it is necessary to register for exams):

❑ First date – ***Thursday June 18, 2020***, 9:00am, teacher's office

❑ Second date – ***Thursday July 2, 2020***, 9:00am, teacher's office

❑ Third date – ***Monday July 27, 2020***, 9:00am, teacher's office

Teaching Material

❏ **Slides** used during lecturing and during guided lab exercises (available for download from the course Web site; the slides will be uploaded progressively as advancing in the topics presentation)

❏ **Suggested Textbooks:**

➢ S. Tarkoma, *Mobile Middleware*, Wiley, 2009

➢ A. Ravulavaru, *Enterprise Internet of Things Handbook*, Packt, 2018

➢ Ke-Lin Du, M.N.S. Swamy, *Wireless Communication Systems*, Cambridge University Press, 2010

➢ R. Meier, *Professional Android 4 Application Development*, Wrox, 2012

➢ A. Goransson, *Efficient Android Threading: Asynchronous Processing Techniques for Android Applications*, O'Reilly, 2014

❏ **Additional on-line sources**:

➢ Public tutorials about Android, iOS, ns-3, fog05, …

➢ Mobile & Pervasive Computing course, Univ. Carnegie-Mellon; Mobile Computing course, Univ. Ohio; Pervasive Computing course, MIT; Mobile Computing course, Virginia Tech; Mobile Computing and Sensor Networks course, NJIT

❏ Associated lab for autonomous exercises: **Lab2**

(students can use it anytime the lab is not occupied for lecturing)

Tools and instruments: usual IDEs, with particular emphasis on Android Studio, to develop middleware/applications for *Android and iOS SDK*, *Ns-3 or Qualnet* (simulators for any-layer protocols), *SUMO* (simulator for vehicular mobility) and *real Android and Raspberry PI devices* (a few units ☺…)

❏ Further development and deployment tools (as well as additional material sources) will be mentioned and described when dealing with the related specific topics

❏ **Receiving hours:**

➢ Bellavista – Tue 2-4pm and Mon 9-11am (after II lecturing term) after appointment via email

➢ Foschini – Mon 4-6pm and Tue 11am-1pm after email

c/o "new" DISI offices – aule nuove building (close to 5.7 seminar room)

➢ E-mail: **paolo.bellavista@unibo.it**, **luca.foschini@unibo.it**

In addition to lecturing and receiving hours:

❑ **The essential reference point is the course Website http://lia.disi.unibo.it/Courses/sm1920-info**

❑ (possibly also) **Course distribution list**: it is a service of the UNIBO portal that allows sending (via e-mail) urgent comunications and additional material to registered students

➢ Access through the same account of "mia e-mail" at: http://www.unibo.it/Portale/Servizi+online/Liste+distribuzione/default.htm

➢ Distribution list name: **sm1920-info**

Generally:

- **on Tuesdays, 4:00pm-6:45pm**
  5.4 seminar room

- **on Thursdays, 3:30pm-6:15pm**
  5.2 seminar room

(any critical overlapping?)

Possible variations will be communicated promptly at the course Website and via the distribution mailing list

Let us start in an interactive and provocatory way...

☐ Examples of «interesting and innovative» mobile systems in 2020?

☐ Which research/work opportunities in mobile systems in 2020?

☐ Which OPEN research challenges in mobile systems in 2020?

When I started this course in 2012, I added some justifications and motivations about:

❑ Suitability of acquiring **competences and skills on mobile communications and services, mobile devices, smartphones, ...**

❑ **Emerging relevance of mobile wireless IoT and connected vehicles**

❑ Suitability of focusing on **Android**

Motivations are still needed ☺ in 2020, after the technological and market evolutions of the last years?

And mobile systems are not only smartphones!

- Market trends in the last 5 years exhibit *impressive growth of smartphones*
  - Availability of very *attractive and responsive applications*
    - Browsers and multimedia players
    - Augmented/virtual reality, location/context-based services
    - Social networking apps
    - Gaming, …
  - Hardware with *increasing performance*, e.g., displays and CPUs
    - Connectivity (4/4.5/5G, Wi-Fi, Bluetooth, …)
    - GPS, magnetoscopes, gyroscopes, sensors, …
    - SSD storage solutions
- Huge *mass market*
  - See the following statistics…

In 2011, the global market scenario was already under definition in a quite clear way:

- If compared with 2010, *sales increased of 42% (previous year of 89%!)*
- *Android devices* were the champions in sales in the last quarter of 2011 (growth of *615%* between 2010 and 2009)
- 115M units sold in 3Q11

OS/platform	3Q11 units	3Q11 Market share (%)	3Q10 units	3Q10 Market share (%)
Android	60490400	**52.5**	20544000	**25.3**
Symbian	19500100	**16.9**	29480100	**36.3**
iOS	17295300	15.0	13484400	16.6
RIM	12701100	11.0	12508300	15.4
Bada	2478500	2.2	920600	1.1
Microsoft	1701900	1.5	2203900	2.7
Others	1018100	0.9	1991300	2.5
Overall	115185400	100	81132600	100

Source: Canalys

Gartner, Nov. 2011

World-Wide Smartphone Sales (Thousands of Units)
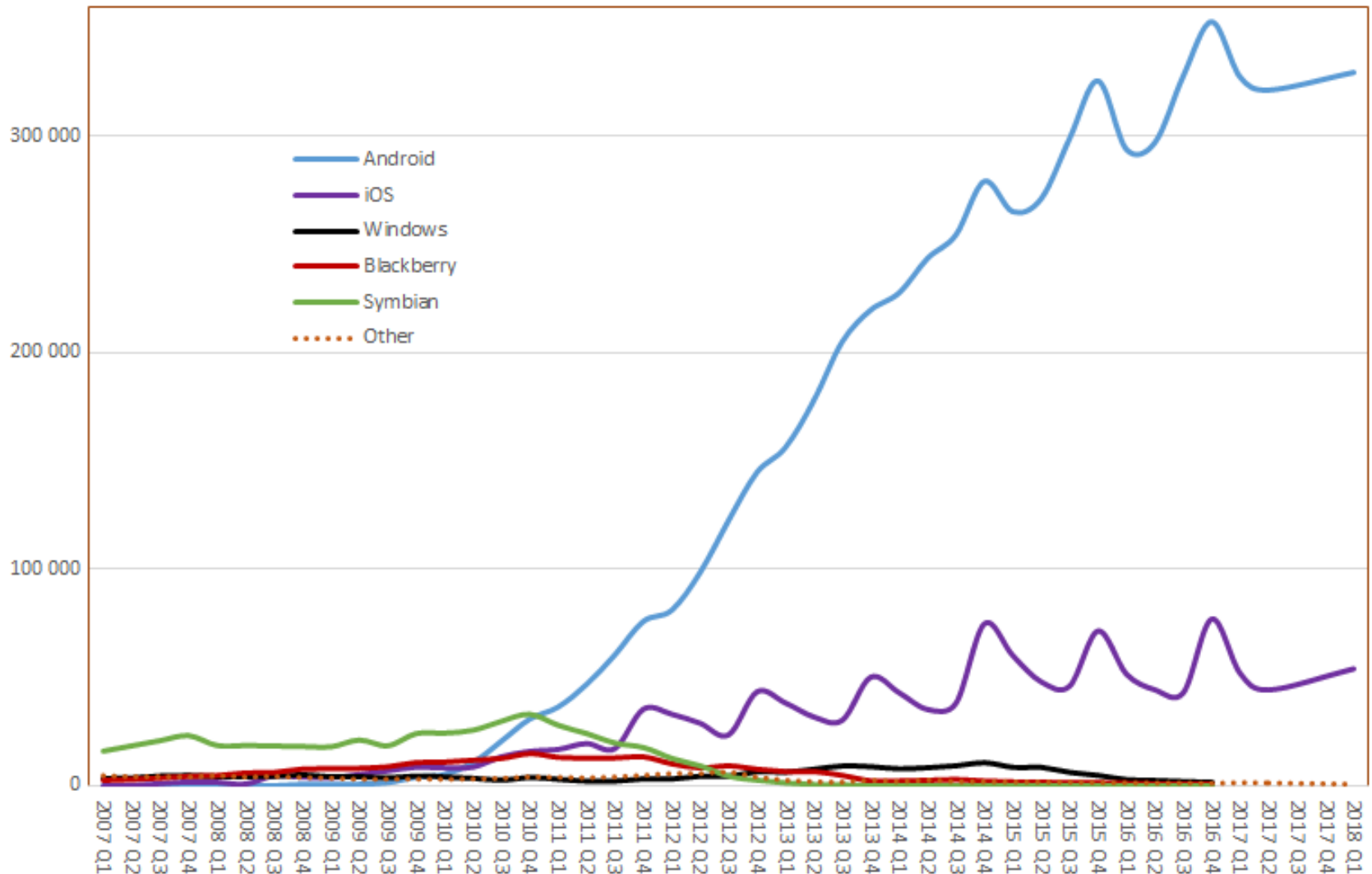
Anyway, Total Unit Shipment in 2019 = around 1200 M !!!

Smartphones fall for sixth consecutive quarter

Worldwide smartphone shipments (quarterly) Q1 2009 to Q1 2019

Source: Canalys estimates, Smartphone Analysis, May 2019

canalys

- ❑ Towards a definition of *mobile computing*, *context awareness* and *middleware*

- ❑ Why mobile computing is NOT AT ALL a commodity but a *great open opportunity* for research and business

- ❑ Mobile computing generates *different requirements* in design/implementation of middleware and sw applications

- ❑ Examples of highly innovative *mobile middleware and services*

- ❑ For instance, possible vision: "*federated islands of edge-enabled*, social-aware, context-aware pervasive mobile services"?

Mobile computing calls for an approach at *multiple layers and with multiple competences/skills*:

- Embedded *devices* (challenges for miniaturization, reduced energy consumption, …)

- *Wireless* communications (IEEE 802.11a/b/g/s/..., Bluetooth, Bluetooth Low Energy, 5G, vehicular protocols, …)

- *Software support platforms* (Android, iOS, SymbianOS, MS?, RIM?, …)

- *Energy management* performed at the sw platform layer (middleware, application, …)

- *Management of multiple het wireless interfaces and handover* at the sw platform layer

- *Context management*

- …

- *…*
- ***Cross-layer management*** of application requirements and resource allocation
- Support to ***infrastructure-based services***
- Support to ***peer-to-peer services***
- Support to ***mobile opportunistic and delay-tolerant services***
- Support to ***mobile social-aware services***
- Support to ***mobile cloud-integrated services in an efficient and smart way*** (in particular Internet of Things)
- ***And design, implementation, deployment and runtime management*** of all these classes of services!

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❑ *Management of multiple het wireless interfaces and handover* at the sw platform layer

❑ *Context management*

❑ …

MIDDLEWARE

- *...*
- *Cross-layer management* of application requirements and resource allocation
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MIDDLEWARE + APPS

Only to mention a few possible examples:

- ❑ *Distribution of dynamically adapted multimedia streaming* towards differentiated smartphones and mobile terminals
- ❑ *Always Best Connected* and *Always Best Served*
- ❑ *Sensors, smart environments* and associated *dynamic adaption of context-aware services*
- ❑ *Collaborative urban monitoring* (vehicular traffic, pollution, usage of vehicles/users that are intrinsically mobile, …) – see MobEyes and COLOMBO
- ❑ *Replication* and *delay-tolerant applications*
- ❑ *Resource sharing based on proximity* – see RAMP
- ❑ *Resource sharing* and *social behaviors*
- ❑ *Efficient 5G and IoT integration through innovative mobile-cloud, cloudlet, fog computing*, … approaches

Now some practical examples to start lightweight ☺ with the course and, most relevant, to stimulate your creativity (not only apps and AppStores…)

MobEyes

http://netlab.cs.ucla.edu/cgi-bin/usemod10/wiki.cgi?MobEyes
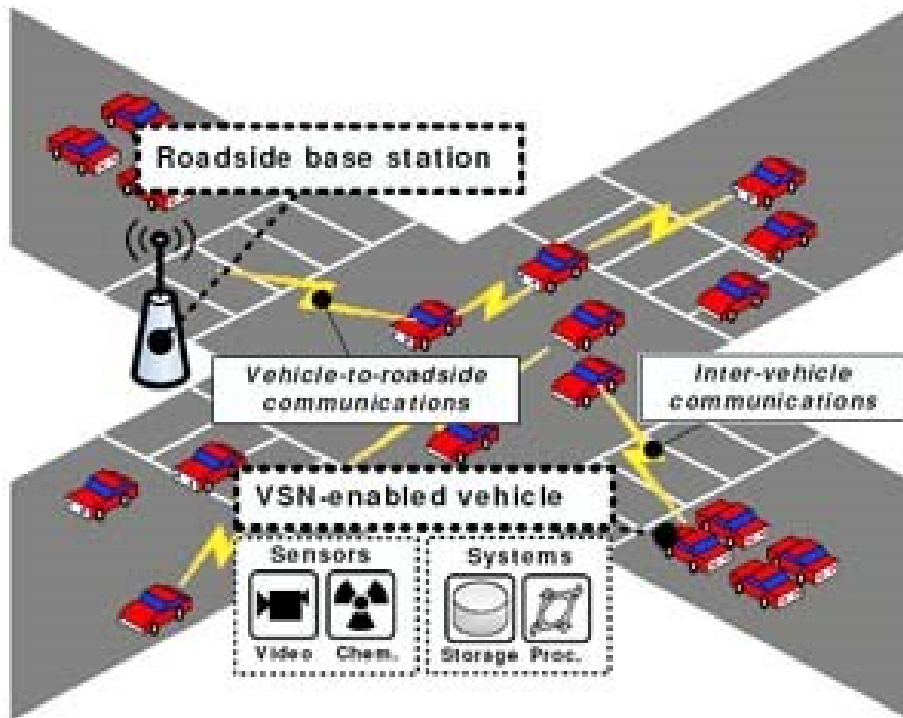
❑ Vehicles perform *opportunistic sensing* of urban environment and keep sensed data locally

❑ *Collaborative dissemination of metadata* based on local autonomous decisions

❑ Possibility of *emerging behaviors* to satisfy *application-specific requirements* (e.g., query completeness, response time, overhead, …)

Urban monitoring through vehicular networks of opportunistic and autonomous sensors

❏ Opportunistic meetings of "regular" vehicles equipped with sensors and wireless communications

❏ Sensor mobility is ***"not-directed"***

Notable differences wrt WSN:
❏ Less stringent constraints on memory, storage, and ***power consumption***
❏ Wide-scale deployment

Application scenario:
❏ Post-crime investigation (e.g., after terrorism attack)
❏ Vehicles with A/V sensors
❏ ***Metadata summaries***
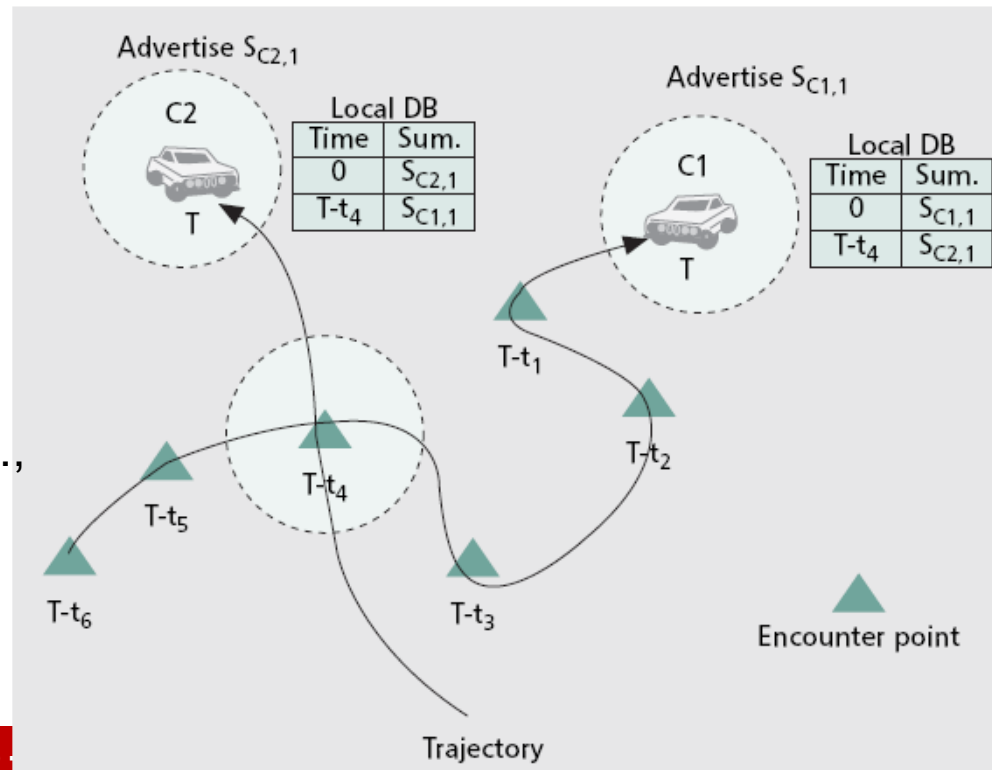
How to induce the desired ***emerging behavior*** with ***minimal and lightweight*** management operations?

❑ Innovative protocols for ***summary diffusion***

➢ Single-hop/k-hop passive diffusion
➢ Single-hop active diffusion

❑ Innovative protocols for ***summary harvesting***

❑ Bloom filters adoption
❑ ***Adaptive tuning*** of protocols depending on ***estimations/ predictions over local properties***, e.g., node density
❑ Extensive ***simulation work*** in realistic deployment scenarios
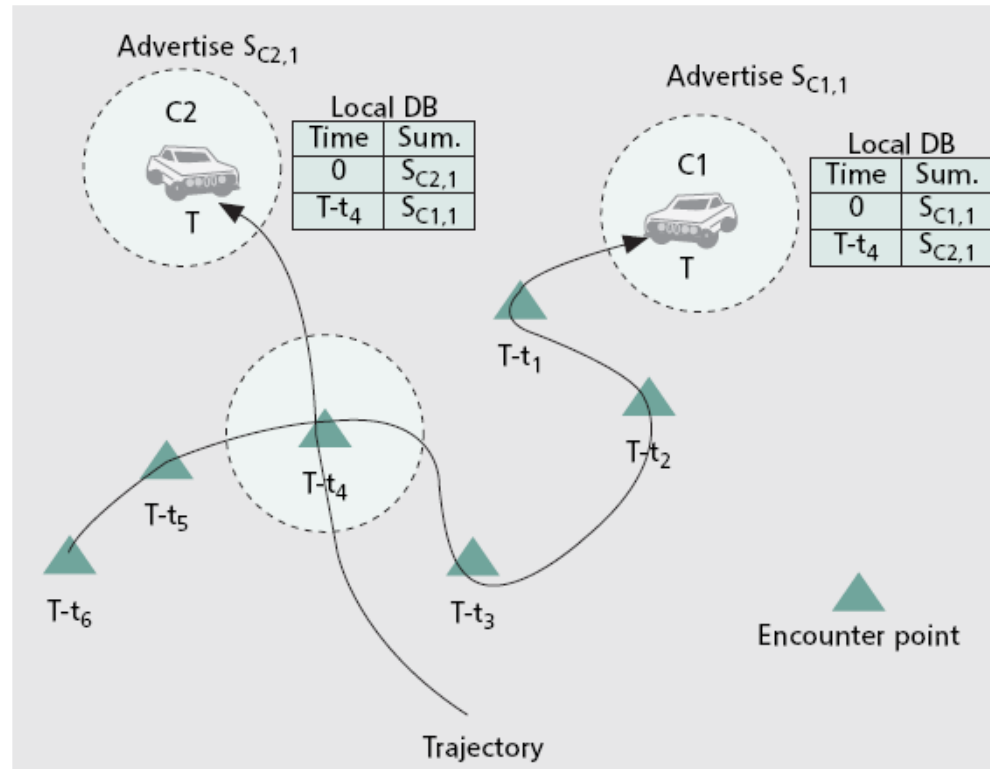
Not only adaptive tuning of protocols for *summary diffusion and harvesting*

→ Goal of *best tradeoff* between *limited overhead limitato and app-specific requirements* (*latency, completeness*, …) in wide-scale environments

How to *coordinate multiple agents* for metadata harvesting? Need for *minimal explicit coordination and minimal overhead*

Bio-inspired Protocols

❑ *Metadata density* (prop. vehicle density) and *datataxis (inpired by chemotaxis di E.coli)*

❑ *Differentiated foraging (Levy jump, biased jump, constrained walk, …)*

❑ *Conflict resolution* (via *stigmergy*, …)

Target zone found   Arrival

Levy Jump   Biased Jump   Constrained Walk

Conflicts, low yield
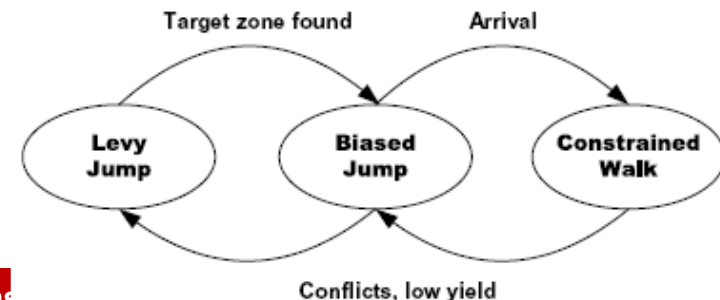
Multi-hop Multi-path Heterogeneous Connectivity (MMHC)

http://lia.disi.unibo.it/Research/MMHC/
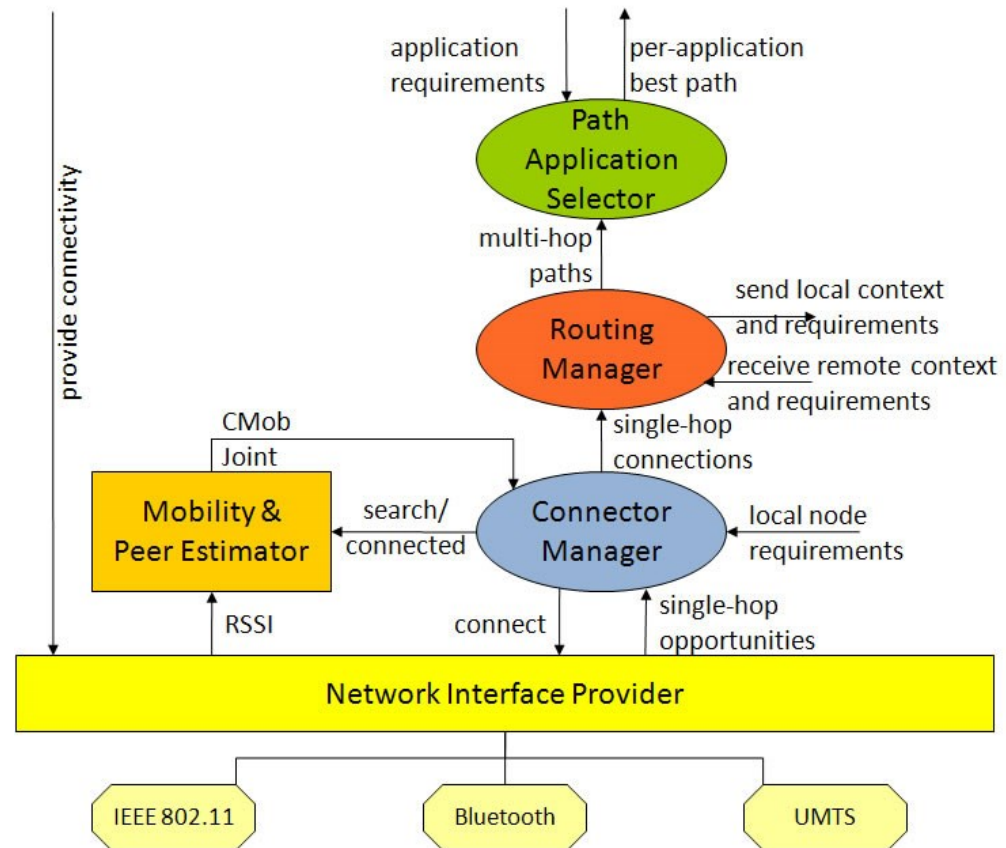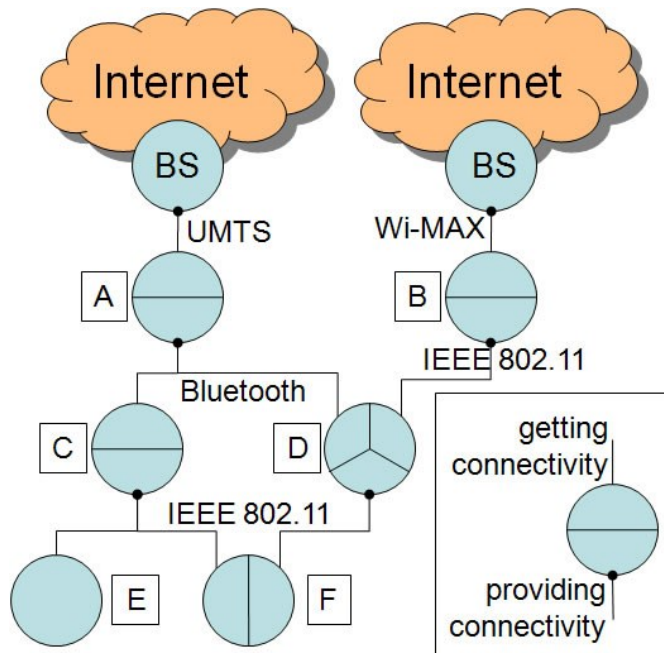
❏ Exploitation of *multiple wireless interfaces at the same time* in different het multi-hop paths, managed at the application level

❏ *Incentives to collaborate* and to share resources

❏ Based on innovative and lightweight *context indicators*, e.g., related to predictions of *joint mobility*, predictions of *throughput*, battery consumption, belonging to *social groups*, …

Additional info about MMHC/RAMP:

☐ http://lia.disi.unibo.it/Research/MMHC/

☐ http://lia.disi.unibo.it/Research/RAMP/

☐ P. Bellavista, P. Gallo, C. Giannelli, G. Toniolo, A. Zoccola: "Discovering and Accessing Peer-to-peer Services in UPnP-based Federated Domotic Islands", *IEEE Transactions on Consumer Electronics*, Vol. 58, No. 3, pp. 810-818, Aug. 2012

☐ P. Bellavista, A. Corradi, C. Giannelli: "Middleware for Differentiated Quality in Spontaneous Networks", *IEEE Pervasive Computing*, Vol. 11, No. 3, pp. 64-75, March 2012

Real Ad-hoc Multi-hop Peer-to-peer (RAMP)

Impromptu interconnection of fixed and mobile nodes

> ➢ Not only to the purpose of Internet connectivity (Always Best Connected - ABC), but also to support users' willingness to *share contents, resources, and services*
> ➢ packet dispatching at the application layer over *het platforms*
> ➢ Management of *non-coordinated IP addressing spaces*

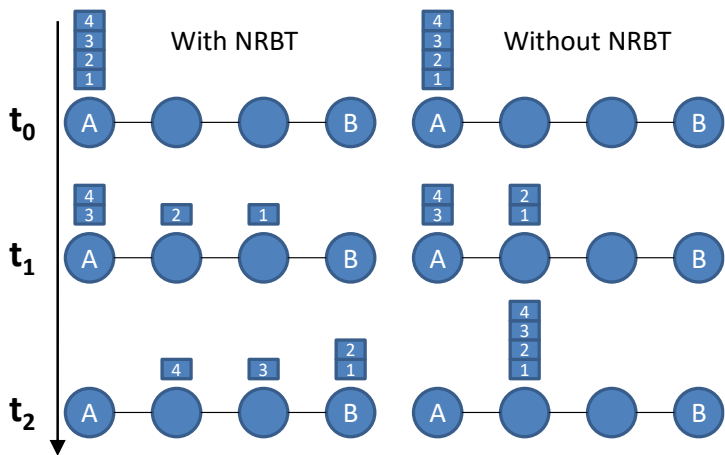RAMP supports the creation and management of *spontaneous networks*

> ➢ *multi-hop* end-to-end connectivity
> ➢ users invoke and offer services (peer-to-peer)
> ➢ *API* to support the *development of novel services* in a simplified way

UMTS Base Station

IEEE 802.11 Access Point

IEEE 802.11 IBSS

Bluetooth Piconet

A C D E

B F G

● interface providing ad hoc connectivity

------ single-hop link

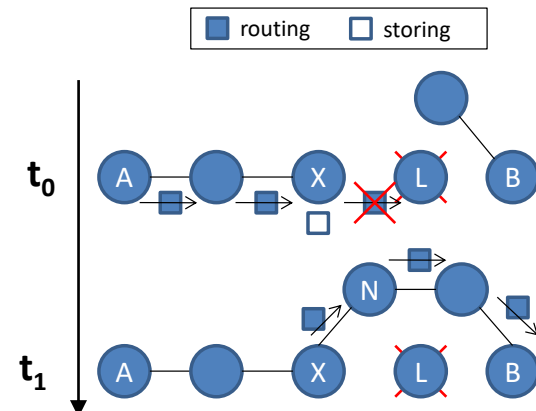IEEE 802.11 IBSS

Bluetooth Piconet
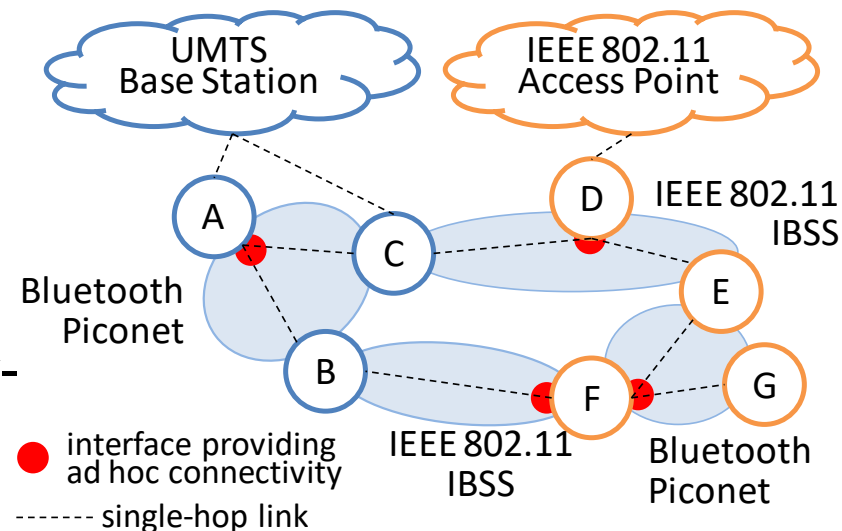
Application-specific Routing
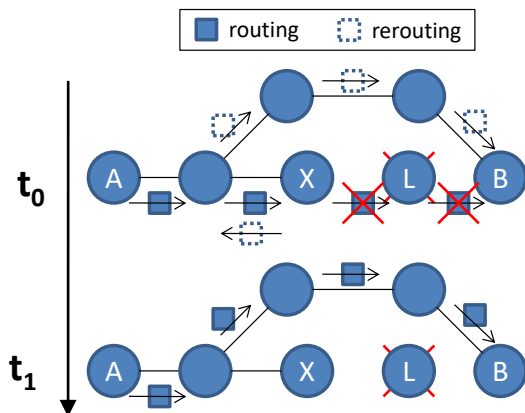
Application developers can specify delivery strategies with ***per-packet granularity***

- ➢ ***Non Reliable Bulk Transfer (NRBT): high performance***, low overhead, low reliability. Based on packet splitting ("large" packets, e.g., for file sharing)
- ➢ ***Reliable Packet Streaming (RPS): to reduce disconnection issues***, (limited) usage of additional resources on partipating nodes (many small packets, e.g., for multimedia streaming)
- ➢ ***Highly Reliable Message Delivery (HRMD)***: maximum availability for ***delay-tolerant services*** but at the expense of memory consumption (delivery of critical messages)

1) Nodes perform end-to-end ***cooperative splitting*** of multimedia paths into different segments

 ➤ reduced traffic on intermediary nodes

2) Nodes perform ***cooperative monitoring of stream quality*** (packet loss, jitter, ...) and ***dynamically adapt*** traversing flows (priority-based video frame dropping)

 ➤ ***fine-grained and per-segment*** management to reduce needed throughput close to dynamically identified bottlenecks

D: Multimedia Dispenser
S: Smart Splitter
H: Dynamic Harvester

main stream
split stream
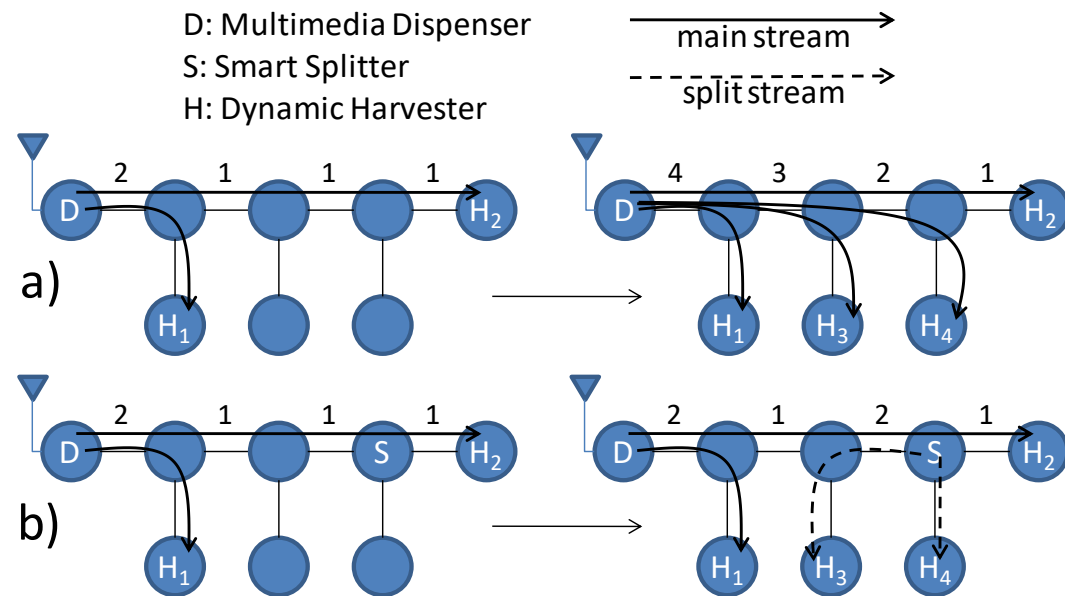
In thousands of Websites and magazines ☺:

❑ By 2020, *around 1.3K IoT devices per person*; most of them able to communicate with the surrounding environment (M2M comms)

❑ Users will benefit from very innovative *smart apps*

❑ *Locazione/space/ambient data* will be available *anywhere*, similarly to other "more traditional" infrastructures (e.g., electric grid)

❑ Connection between *real physical world and "cyber world"* can relevantly enrich the user experience

❑ "Internet-like" revolution for the *physical space Cyber Physical Systems*

❑ Towards a *common and open way* to access smart space data from smart devices

❑ Applications emerging from composition and *local mash-up*, based on devices and data of *open smart spaces*

Towards *information-level interoperability*

In collaboration with several international research groups:

- Dartmouth, USA
- NJIT, USA
- Univ. Santa Catarina and others, Brazil

- Smartphones as routing infrastructure for WSN
- Smartphones as personal sensors *BeWell*
- Participaction in urban tasks – *ParticipAct* http://participact.unibo.it

Not only wide-scale pervasive systems (*smart city*), but also strong push towards *COLLABO-RATIVE sharing*

personal space

urban space

social space

Courtesy:MetroSense, A. Campbell

☐ Social sharing of *sensed data*

☐ Social sharing of *available and under-utilized resources*

Telephony
- CDR processing
- Social analysis
- Churn prediction
- Geomapping

Stock market
- Impact of weather on securities prices
- Analyze market data at ultra-low latencies

Transportation
- Intelligent traffic management
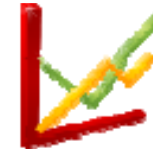
Law Enforcement, Defense & Cyber Security
- Real-time multimodal surveillance
- Situational awareness
- Cyber security detection

Smart Grid & Energy
- Transactive control
- Phasor Monitoring Unit

Fraud prevention
- Detecting multi-party fraud
- Real time fraud prevention

e-Science
- Space weather prediction
- Detection of transient event
- Synchrotron atomic research

Health & Life Sciences
- Neonatal ICU monitoring
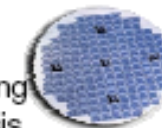- Epidemic early warning system
- Remote healthcare monitoring
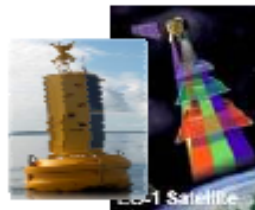
Natural Systems
- Wildfire management
- Water management

Other
- Manufacturing
- Text Analysis
- Who's Talking to Whom?
- ERP for Commodities
- FPGA Acceleration

- Project Title: Distributed Digital Twins for industrial SMEs: a big-data platform

- Project Acronym: **IoTwins**

- Grant Agreement Number: 857191

- Duration: 36 months

- Total Budget: €20,029,818.75

- Total EC Contribution: €16,422,552.01

COORDINATOR:

Bonfiglioli Riduttori Spa

Bonfiglioli
Forever Forward

IoTwins Consortium:
the synergy of 23 Partners in 8 Countries

10 Universities, Research Institutes, Associations

9 Manufacturing and electronics companies

4 Service Companies

IoTwins concept and ambition

Distributed and <u>Edge-based Industrial Twins for SMEs</u>: a Big Data Platform

To *lower the barriers* for *edge-enabled and cloud-assisted intelligent* systems and services based on big data for domains of *manufacturing and facility management*

Barriers:

- AI-based solutions require mastering *complex and rapidly evolving tools and techniques*, introducing delays and costs in product/process design, deployment, test, and refinement

- Effective deep learning requires access to *very large sources of curated data*, as well as *significant computational resources* for training

- Execution and online refinement of learned models often need to be at the *premises of big data sources (latency and reliability requirements, adequate degree of data privacy*, …)

- Investments in infrastructure at server/edge sides, …

IoTwins concept and ambition

Ambition

Build a reference architecture for distributed and edge-enabled digital twins
- Implementation, deployment, integration, and experimental in-the-field evaluation in several test-beds

Digital twins *to detect and diagnose anomalies*, to determine an optimal set of actions that *maximize key performance metrics*, to enforce *on-line quality management of production processes* under *latency and reliability* constraints, and to provide predictions for strategic planning, and to create new services and business models

IoTwins proposes a hierarchical organization and inter-working of digital twins:

- IoT twins
- Edge twins
- Cloud twins

INDUSTRIAL *PLANT - FACILITY*

Edge nodes

Cloud resources

PLANT - FACILITY MANAGER

- On-line optimization
- Anomaly detection
- *Digital twin on IoT*

DIGITAL TWIN ENABLED SERVICES

- Predictive Maintenance & Production Optimization
- Facility Management & Facility Planning

- Maintenance plans
- Facility management
- Plans Actions

Industrial devices, Sensors, and PLC

Actuation

- On-line optimization
- Anomaly detection
- *Digital twin on IoT*

- IoT management
- Trained ML models
- Locality on-line optimization
- *Digital twin on the edge*

- Trained ML models
- Off line stochastic optimization on the cloud
- Agent based simulation on the cloud
- Physic models simulation on the cloud
- *Digital twin on the cloud*

- Data aggregation
- Anonymization
- Local actuation

Components for Digital twins

- Training of ML models
- Agent-based modelling
- Physics system modelling
- System Characterization for off line optimization
- Empirical model learning

Data streams

Data streams

PLC

Industrial IoT

High performance computing and storage resources

HPC-Big Data infrastructure

Approach and methodology
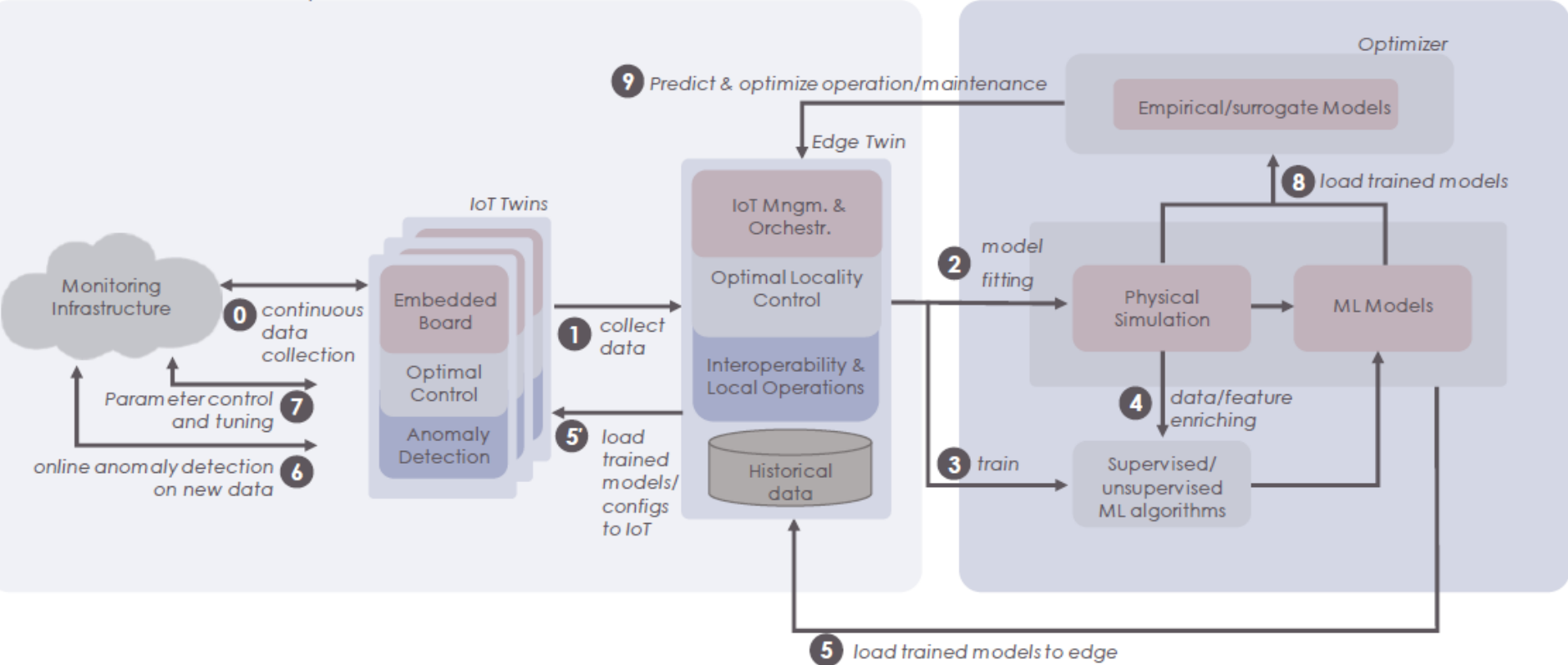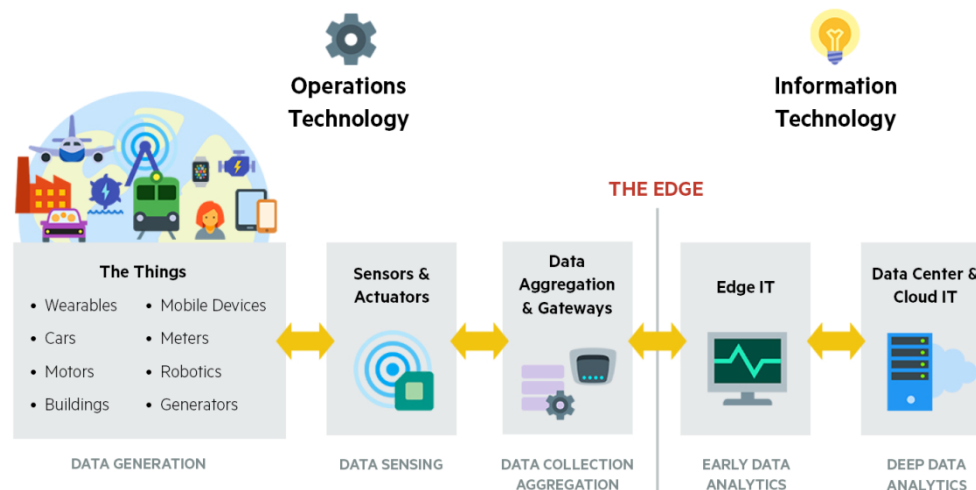
Crowdsensing, Internet of Things, always connected devices, smart cities, …

mobility RELEVANTLY affects the efficiency of

- ☐ ***Online stream processing***
  collaborations with IBM, CRIF, …

- ☐ ***Mobile-to-cloud integration*** (<u>fog computing, edge computing, mobile edge computing, cloudlet</u>, …)
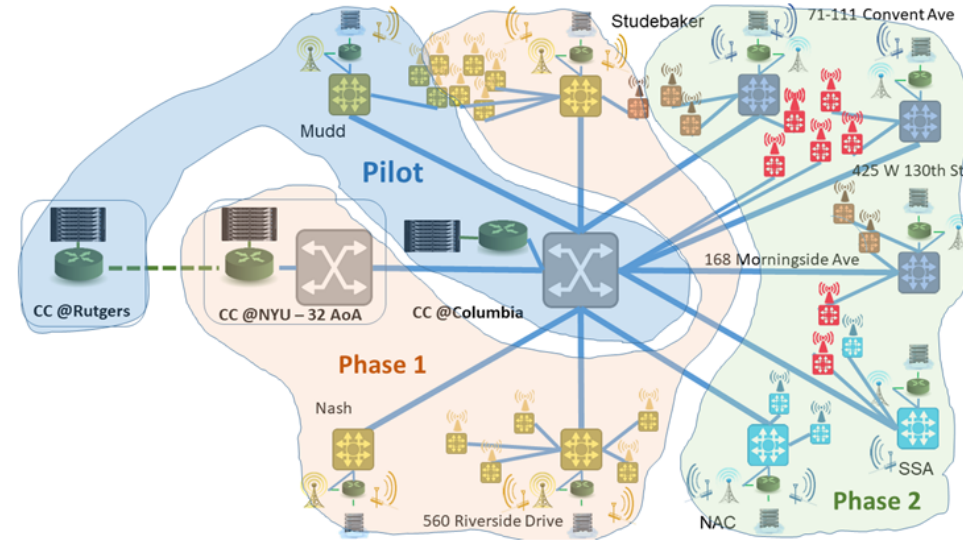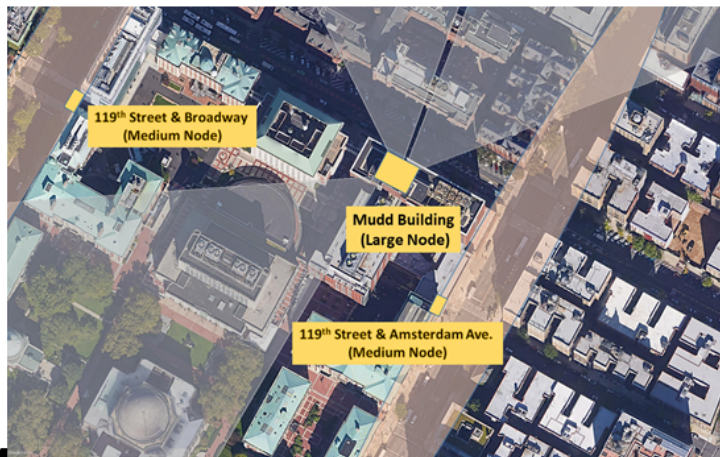 collaborations with Fraunhofer, TUB, Adlink, UPMC, …

COSMOS Deployment: NYC Coverage Areas

- Pilot – planned for end of 2018
- Phase 1 in 2019, Phase 2 by 2020

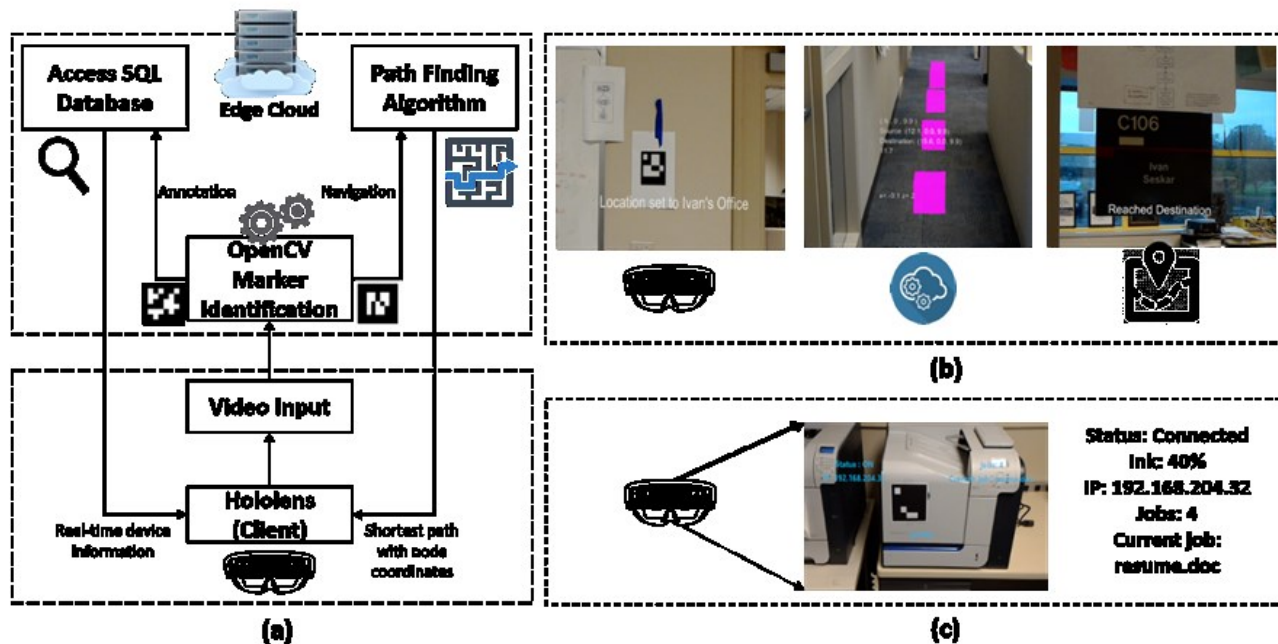- Phase 1 Columbia/CCNY – ~15-20 nodes
- Phase 2 – ~40 nodes

COSMOS Experiments: AR Applications

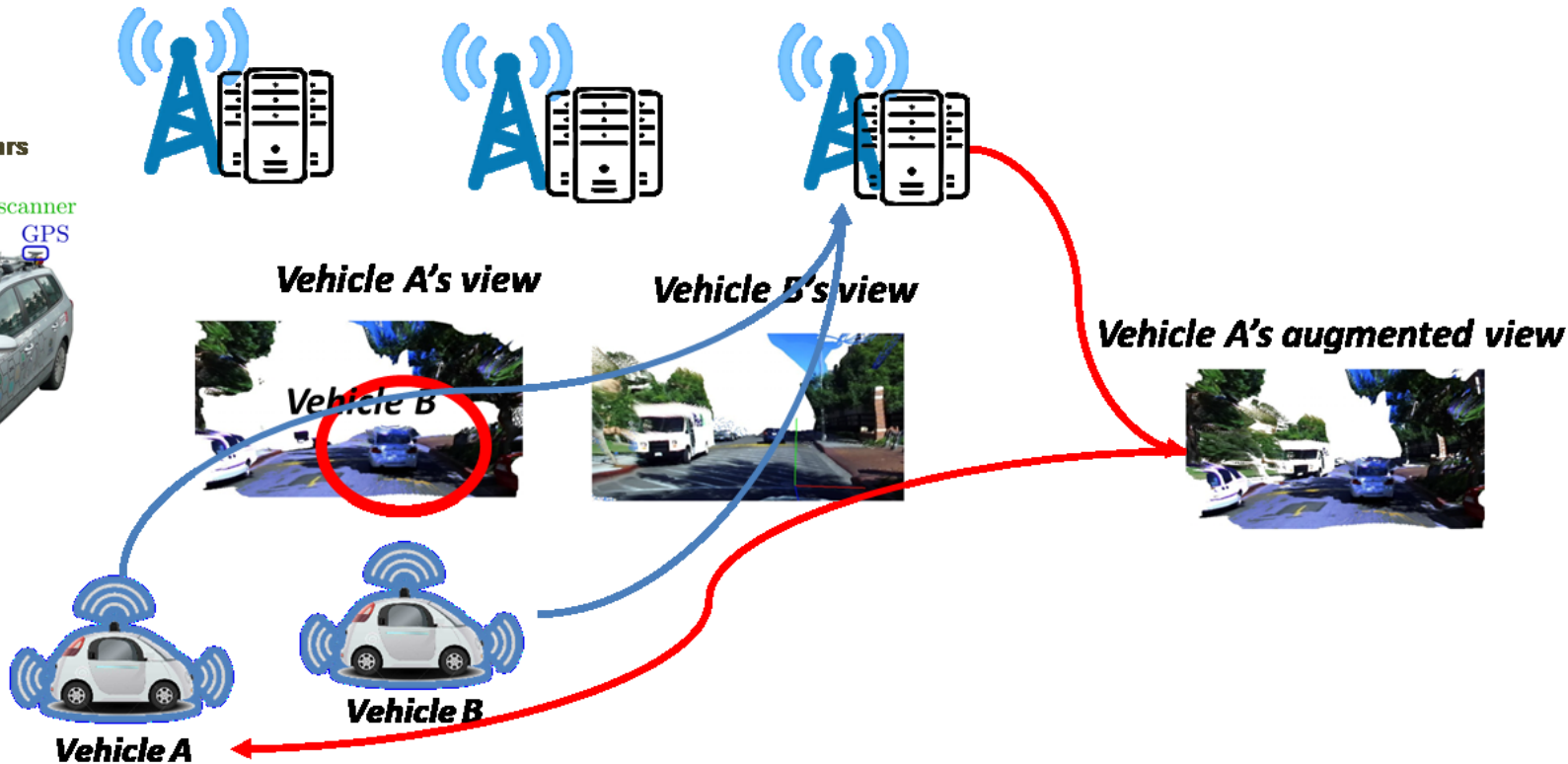(a) AR application flow; (b) Smart meeting application using indoor navigation; (c) Annotation based assistance

Operations Technology

Information Technology

THE EDGE

The Things
- Wearables
- Cars
- Motors
- Buildings
- Mobile Devices
- Meters
- Robotics
- Generators

Sensors & Actuators

Data Aggregation & Gateways

Edge IT

Data Center & Cloud IT

DATA GENERATION

DATA SENSING

DATA COLLECTION AGGREGATION

EARLY DATA ANALYTICS

DEEP DATA ANALYTICS

NOT a COMMODITY!!!