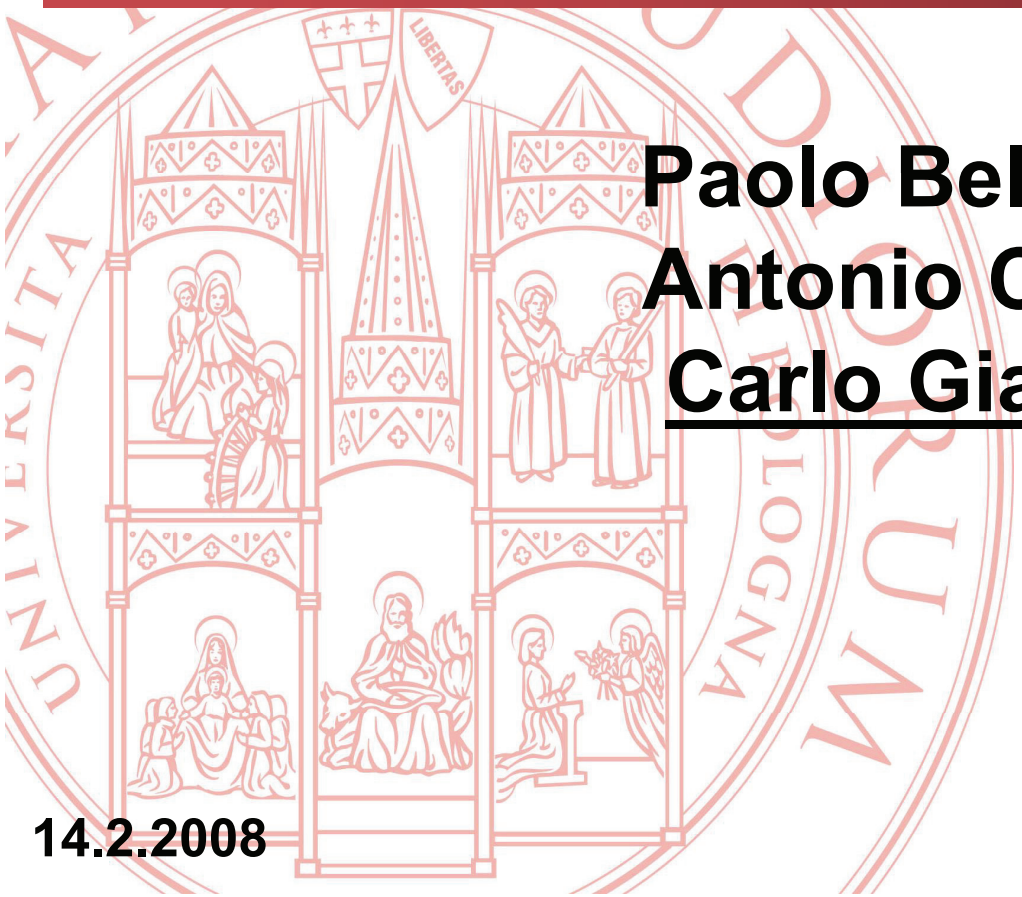
A Layered Infrastructure for Mobility-Aware Best Connectivity in the Heterogeneous Wireless Internet



Paolo Bellavista
Antonio Corradi
Carlo Giannelli

14.2.2008

DEIS, Università degli Studi di Bologna,
Viale Risorgimento, 2 - 40136 Bologna Italy
carlo.giannelli@unibo.it

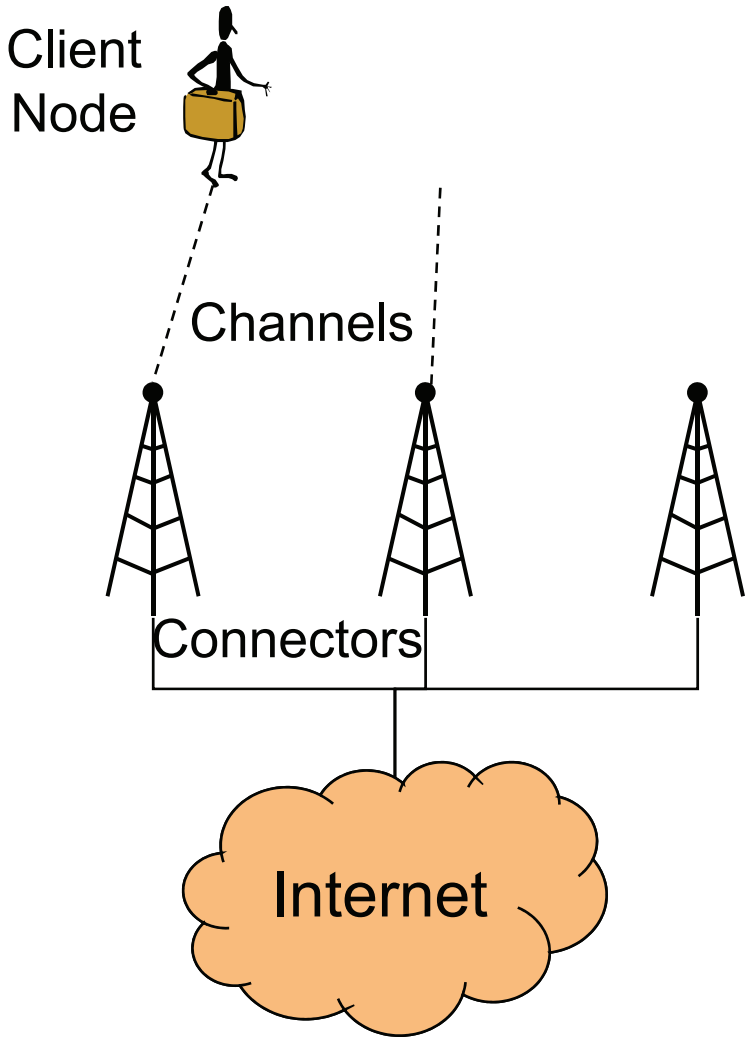
Agenda

- From traditional homogeneous to novel **heterogeneous** Wireless Internet
  - several communication technologies
  - infrastructure and peer points of access
- **Mobility-Aware Connectivity (MAC)** middleware for **context-aware** dynamic **networking opportunity management**
  - context information: exploited technology, **infrastructure/peer** point of access, client node and peer **mobility**, OS/user/application requirements
  - **two-layer architecture**
    - bottom-layer: **reliable** remote connection **establishment**
    - top-layer: per-application connection **selection**

The Wireless Internet (WI)

- **Client** node: node **requiring** connectivity, e.g., user PDA
- **Connectors**: nodes **providing** connectivity, e.g., UMTS base station
- **Channel**: active client-connector IP connection, e.g., IEEE 802.11 association and DHCP configuration

- **Handover procedure**
  - a client node **changes** current **connector** while moving
- **Evaluation process**
  - **context gathering**: which information is important?
  - **metric application**: which is the most suitable connector?

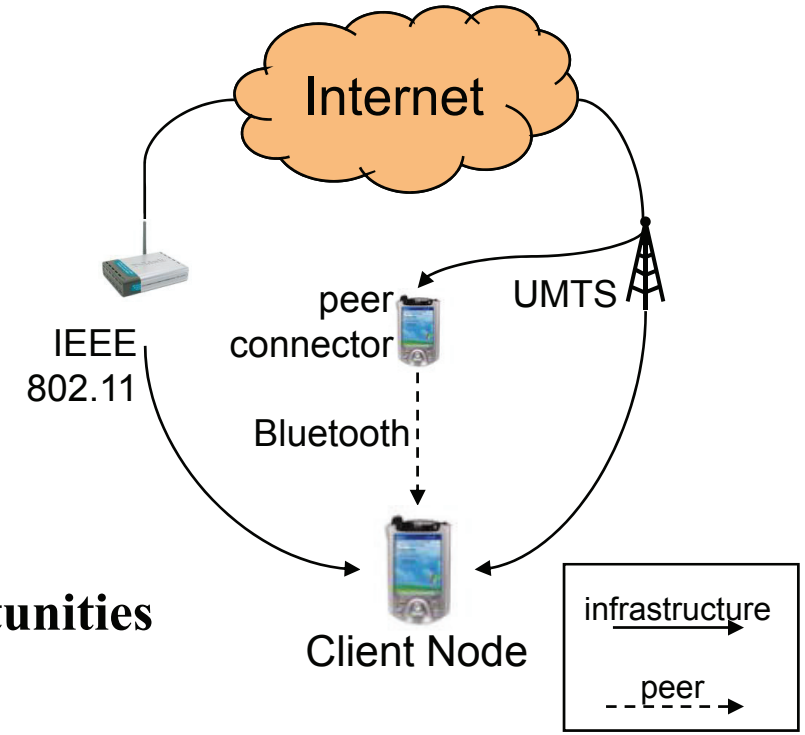


Homogeneous WI

- **One** communication **interface** at a time
  - the client node does not change wireless interface
- **Horizontal handover**
  - infrastructure connectors only
  - origin and destination connectors based on the same wireless technology
- IEEE 802.11
  - connectors are IEEE 802.11 access points
  - metric based on Received Signal Strength Indication (RSSI) and Signal to Noise Ratio (SNR), usually embedded in interface firmware

Heterogeneous WI

- **Heterogeneous interfaces**
  - the client node exploits **multiple wireless** interfaces, even simultaneously
- **Heterogeneous connectors**
  - can be **infrastructure** or **peer** nodes
- **Channel management**
  - managing interfaces/connectors/channels considering **several context data** to take advantage of the **many networking opportunities**



- The **heterogeneous WI increases** client node **capabilities**:
  - heterogeneous connectors provide a **more suitable** connectivity
    - Bluetooth to limit power consumption, IEEE 802.11 to get greater bandwidth
  - peer connectors **extend connectivity** opportunities
    - UMTS link accessed via Bluetooth through a peer connector

Heterogeneous WI: Issues

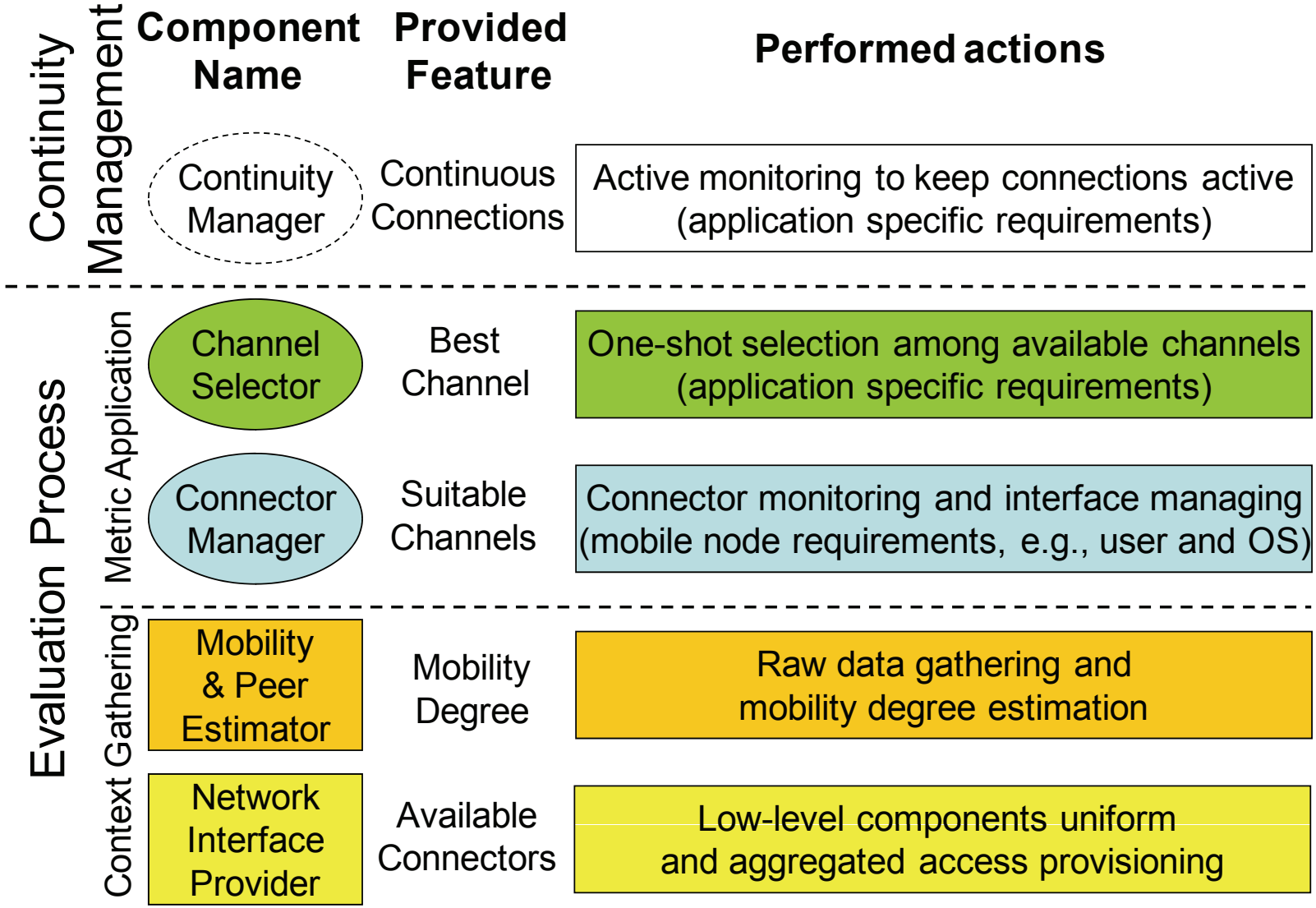
- Novel **metric** considering a wide set of information at different abstraction levels
  - **traditional** RSSI/SNR based **evaluation processes are not enough**
- **Heterogeneous** wireless **interfaces** characteristics
  - bandwidth (IEEE 802.11), coverage range (UMTS)
- **Connectors** peculiarities
  - peer connectors are **less reliable**, since may abruptly **interrupt** the connectivity or **move away**
- **OS/user/application** eventually **conflicting requirements**
  - applications may require **great bandwidth** (IEEE 802.11) while OS could desire to **minimize power consumption** (Bluetooth)

Mobility-Aware Connectivity MAC

- **Evaluation metric** specifically designed for heterogeneous WI scenarios
  - wireless technology characteristics, e.g., bandwidth, coverage range, power consumption
  - **client node and peer mobility** to provide **durable/reliable channels**
  - context information directly available on the client node → MAC middleware is **autonomous** and decentralized

- **Two-layer** architecture to **separately** considering channel **establishment** and **selection**
  - **bottom**-layer metric: which connectors are suitable for **channel realization** considering the **whole client** node requirements
  - **top**-layer metric: which is **the best channel** among available ones considering each **application** separately

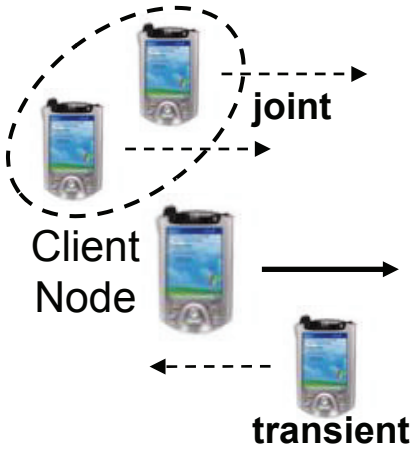
MAC Logical Organization



Mobility and Peer Estimator (1)

- **Transient** connector
  - e.g., a mobile node in the same sidewalk but with opposite direction
  - **not suitable** for connectivity since has a high probability of **becoming unavailable**
- **Joint** connector
  - e.g., PDA connector in the same train wagon
  - **greater durability** → **suitable** for connectivity

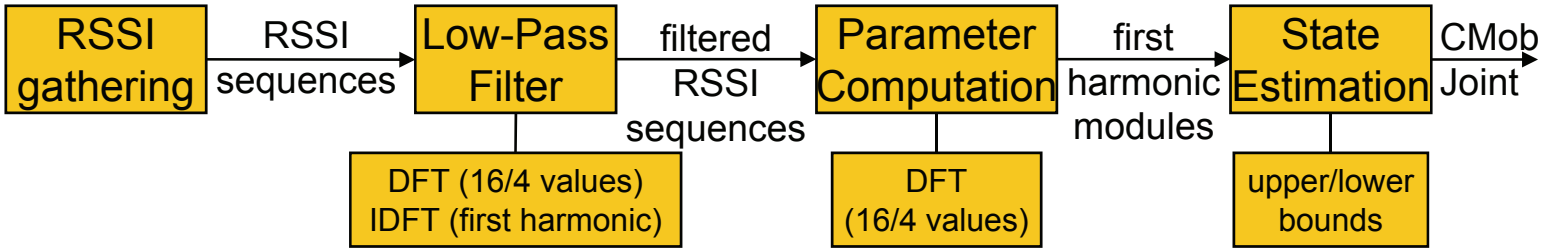
- Client node-connector **mutual distance** inferred monitoring connector **RSSI variability**
  - **CMob** to evaluate **client** node mobility degree [0,1]
  - **Joint** to evaluate peer **connector** relative mobility degree [0,1]



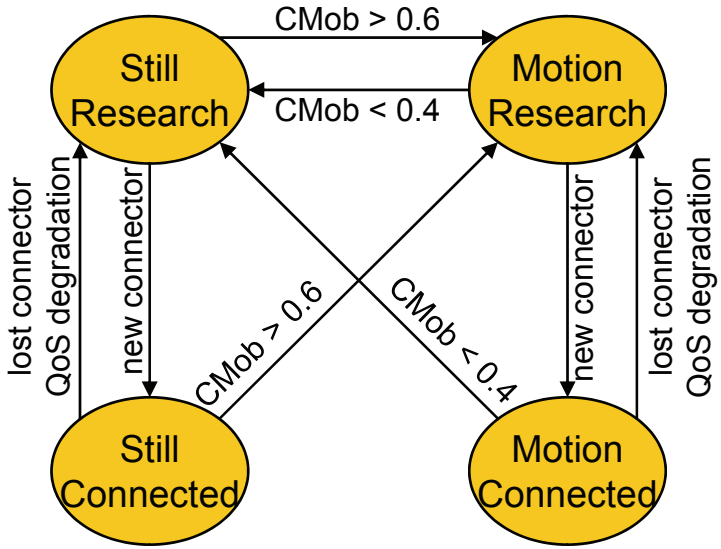
Connector type	RSSI variability	Mobility state
fixed	almost constant	still client node
	greatly variable	moving client node
mobile	almost constant	joint connector
	greatly variable	transient connector

Mobility and Peer Estimator (2)

- **Discrete Fourier Transform (DFT)** applied twice to
  - low pass **filter RSSI fluctuations** due to signal noise
  - estimate **CMob** (fixed infrastructure connectors) and **Joint** (peer connectors)



- **Adaptive monitoring** to reduce costs
  - research or motion: **aggressive** monitoring to find a connector as soon as possible
    - frequent monitoring of nearby connectors
  - connected and still: **lazy** monitoring to understand if relevant events happen
    - frequent monitoring of the current connector and occasional monitoring of other connectors



Connector Manager

- Interface behavior control → **potentially harming the client node**
  - e.g., exploiting consuming wireless interfaces when the battery level is low
- Consider **whole** client **context/requirements**

- ***ConnectorValue*** = *EnduranceValue* + *MetricSpecificValue*
  - **EnduranceValue**: expected connector **durability**
  - **MetricSpecificValue**: other parameters related to the **whole** mobile client

Connector Type	EnduranceValue	MetricSpecificValue
fixed connector	CMob • Range	(1-CMob) • ((1-α-β) + α · Energy + β · Trust)
mobile connector	(1-Joint) • Range	Joint • ((1-α-β) + α · Energy + β · Trust)

- **Mobile** client node (CMob≈1) or **transient** peer connector (Joint ≈ 0)
  - connector **Range** to **maximize connection durability**
- **Still** client node (CMob ≈ 0) or **joint** peer connector (Joint ≈ 1)
  - **additional requirements** related to the whole client node, e.g., power consumption and level of trust in relation to user requirements α and β

Channel Selector

- **On-demand channel** evaluation and **selection** in relation to **per-application** requirements
  - **lower priority** than Connector Manager
  - channels provided by Connector Manager are suitable for the whole mobile client, e.g., ensure a certain degree of durability

- $\textit{ChannelValue} = x \cdot \textit{EnduranceValue} + y \cdot \textit{MetricSpecificValue}$
  - **EnduranceValue**: estimated channel durability
  - **MetricSpecificValue**: parameters related to **channel condition**, e.g., bandwidth, jitter

- Application requirements (x/y) to prioritize reliability or other parameters
  - file **downloading**: x=0, y=1 → **larger bandwidth** despite its endurance
  - **interactive** application: x=1, y=0 → the most **durable channel**

MAC Performance Results

- Simulations to test **several deployment environment** in relation to mobile client **speed** and **RSSI noise** standard deviation
  - **Hit Rate$_{\%}$**: rate of correctly estimated still/motion state
  - **Responsiveness (s)**: time between actual and perceived state change
  - **Long Time Hit Rate$_{\%}$**: Hit Rate not considering samples in a 5s-long window after state change, i.e., neglecting the transitory phase due to low-pass filtering delay
- Great performance after 5s-transition period
- Only very relevant RSSI noise decreases performance results

RSSI Std. Dev. (dB)		**1**			**3**			5		
Average Speed (m/s)		**1.0**	**2.0**	**3.0**	**1.0**	**2.0**	**3.0**	**1.0**	**2.0**	**3.0**
Hit Rate (%)		72	73	73	70	73	67	65	61	53
Respon-	average	13.5	4.7	4.3	12.8	5.2	5.1	9.6	9.9	9.3
siveness (s)	std. dev.	12.7	1.3	1.9	10.0	3.2	2.9	7.5	6.4	6.0
Long Time Hit Rate (%)		84	99	97	85	96	94	78	74	65

Conclusions & Ongoing Work

- MAC proposes a **novel evaluation process** suitable for heterogeneous WI scenarios considering
  - **wireless** technologies and **connector types**, e.g., infrastructure/peer
  - novel expressive **context information**, i.e., client node/peer **mobility**
  - **two-layer architecture** to separately consider OS/user and application requirements
    - **bottom-layer** to **establish channels** with nodes suitable for the **whole client**
    - **top-layer** to **select** the most suitable channel in a **per-application** fashion
- Ongoing work:
  - **security** issues: peer mutual authentication, user incentives, dynamic level of trust management
  - **continuity management**: continuous connectivity abstraction to the application layer

Any question?

- Prototype code and implementation insights:
  - http://lia.deis.unibo.it/research/**MAC**/
  - http://lia.deis.unibo.it/research/**MACHINE**/
  - http://lia.deis.unibo.it/Staff/CarloGiannelli/