Context-aware Middleware for Reliable Multi-hop Multi-path Connectivity

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Agenda

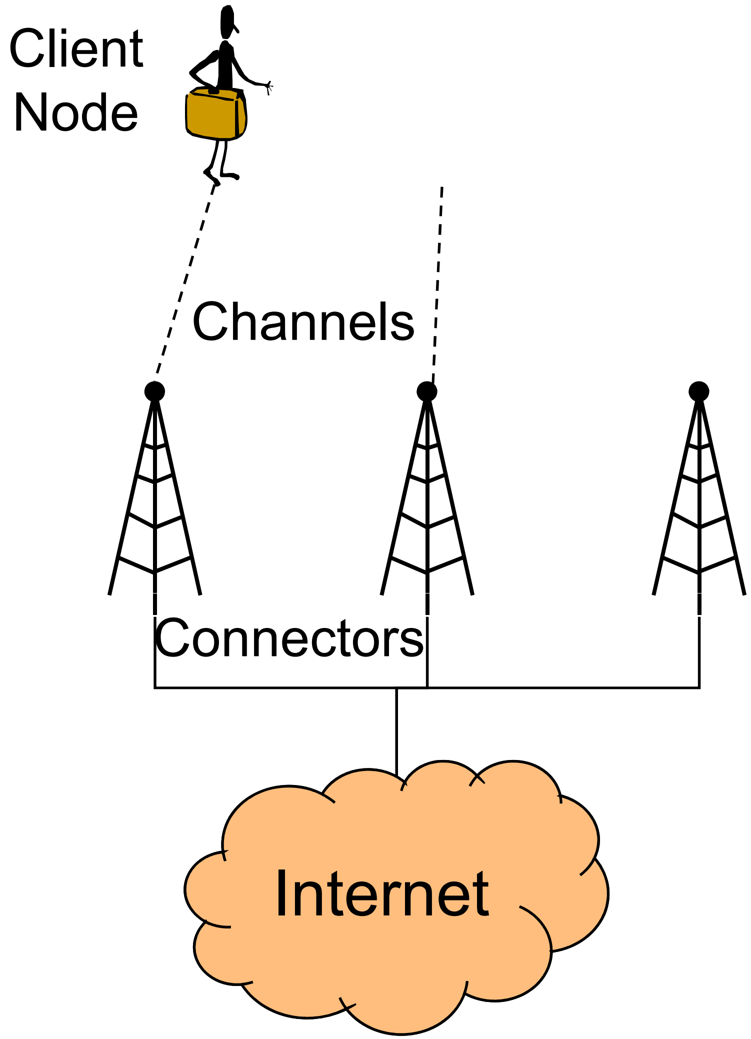
- From traditional homogeneous to novel **heterogeneous** wireless scenarios
  - several communication technologies
  - infrastructure and **peer** points of access

- **Multi-hop Multi-path Heterogeneous Connectivity (MMHC)** middleware for **context-aware** dynamic **reliable connections** to the Internet
  - **context information**: node mobility, path throughput, energy availability
  - **two-phase procedure**
    - local-phase: **reliable** remote connection **establishment**
    - global-phase: available paths enhancing to ensure **long-term availability**

The Wireless Scenario

- **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?

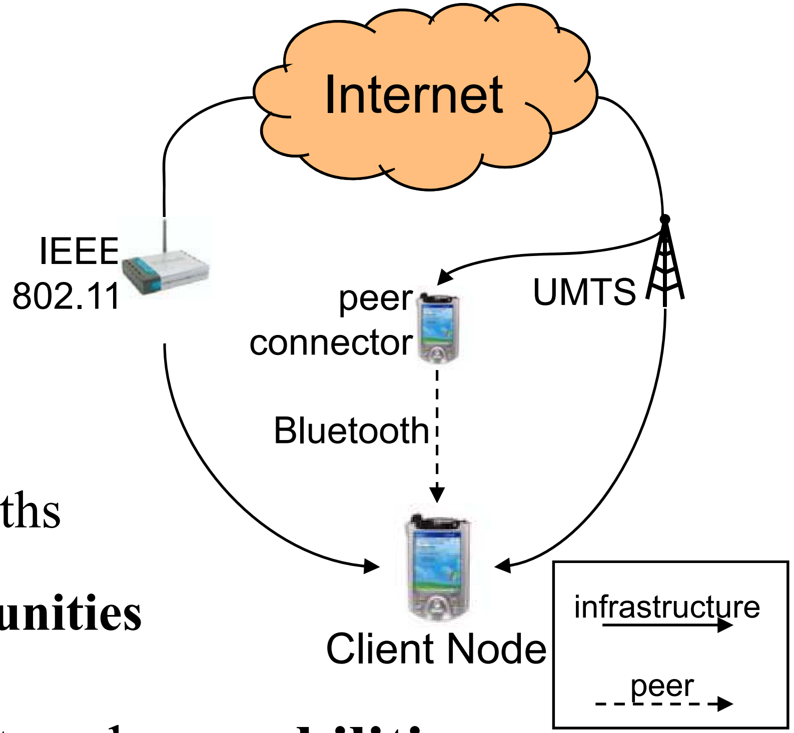


Homogeneous Wireless Scenario

- **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 Wireless Scenario

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



- **Wireless heterogeneity increases** client node **capabilities**:
  - heterogeneous connectors enable the **most suitable** form of connectivity
    - Bluetooth to limit power consumption, IEEE 802.11 to get larger bandwidth
  - peer connectors **extend connectivity** opportunities via multi-hop **paths**
    - UMTS link accessed via Bluetooth through a peer connector

Heterogeneous Wireless Scenario: Issues

- Novel metric considering a wide set of information at different abstraction levels
  - traditional RSSI/SNR based evaluation processes are not enough

- Provide **highly reliable paths** (crucial issue in mobile wireless networks) with **sufficient quality** (to maximize user satisfaction)
- Path reliability
  - peer connectors are less reliable, since may abruptly **move away** or interrupt the connectivity to limit **power consumption**
- Path quality
  - wireless **technology**, number of **active clients**, and number of **hops** to the Internet may degrade achieved **throughput**

MMHC: Multi-hop Multi-path Heterogeneous Connectivity

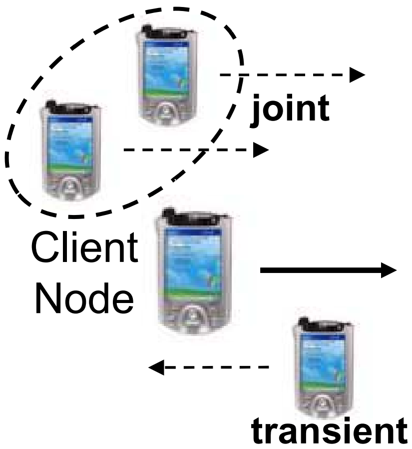
- **Evaluation metric** specifically designed for heterogeneous wireless scenarios
  - client node and peer **mobility** to provide **reliability**
  - wireless technology and path characteristics, e.g., bandwidth and number of clients at each hop, to provide **sufficient throughput**
  - **residual battery** level to ensure path **long-term durability**

- **Two-phase** procedure to separately consider path **establishment** and **enhancement**
  - **local-phase**: connectors suitable for **path realization** to maximize reliability and throughput
  - **global-phase**: **long-term connectivity** based on additional context information, eventually slight modifications of the network topology

Node Mobility (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

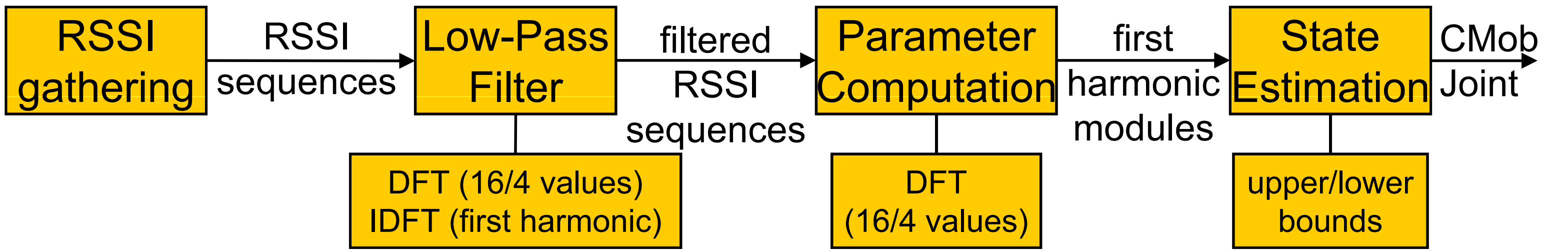
- Client-connector **mutual distance** inferred by monitoring connector **RSSI variability**
  - **CMob** to evaluate **client** node mobility degree [0,1]
  - **Joint** to evaluate peer **connector** relative mobility degree [0,1]



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

Node Mobility (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)



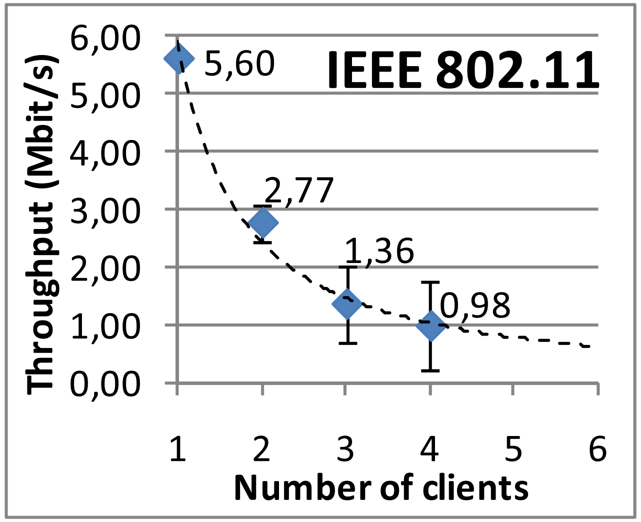
- Single-hop: **EstimatedEndurance**
  - (1-CMob) • CoverageRange (for APs/BSs)
  - Joint • CoverageRange (for mobile peers)

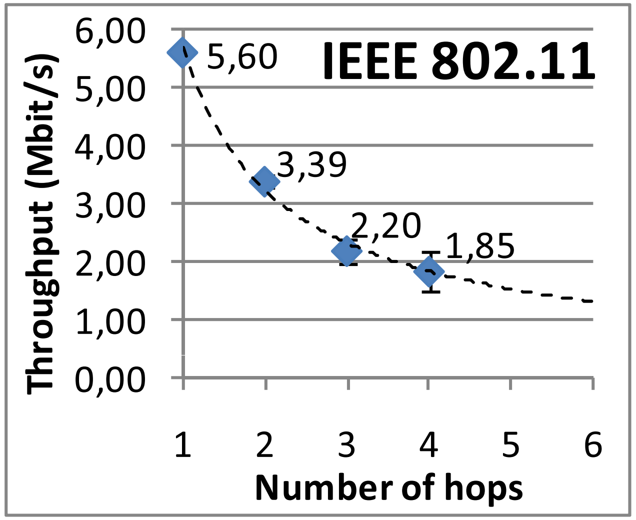
- Multi-hop: **PathMobility** at k^{th} hop
  - $EstimatedEndurance_k$ (single-hop, i.e., k=1)
  - $EstimatedEndurance_k \bullet PathMobility_{k-1}$ (multi-hop, i.e., k>1)

- Lessons learned: push for paths composed by **joint nodes**

Path Throughput (1)

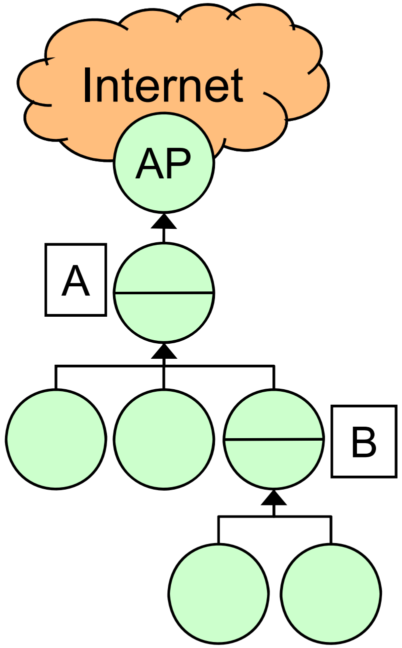
- Coarse-grained estimation of **multi-hop paths throughput**
  - adopted **wireless technology**: e.g., Bluetooth represents a bottleneck
  - number of **active clients**: fair bandwidth sharing
  - number of **hops** to the Internet: 20-30% per-hop degradation





- **Heterogeneous wireless interfaces** provided by different manufactures, e.g., IEEE 802.11 Orinoco Gold, Buffalo and PRO/Wireless interfaces
  - heterogeneous interfaces better mimics actual wireless environments
  - greater performance with homogeneous hardware

Path Throughput (2)



- EstimatedThroughput (ET):
  - NominalBandwidth (NB) (for APs/BSs)
  - (1 – HopDegr) • MaxThr / #clients (for mobile peers)
    - where MaxThr=min{previous hop ET, current hop NB}

  - $ET_{AP} = NB_{AP} = 4$ Mbps
  - ET_{A} = (1-0.2) • 4 Mbps / 3 clients = 1.07 Mbps
  - ET_{B} = (1-0.2) • 1.07 Mbps / 2 clients = 0.428 Mbps

- Lessons learned: push for **short paths** with **few clients**, particularly when exploiting Bluetooth

Energy Availability (1)

- Expected **long-term path durability** due to **energy consumption**
  - avoid paths composed by mobile peers with **low battery levels**
    - probably unavailable in a short time
  - **fairly exploit energy** of mobile peers not overloading only one path
    - traversing traffic increase power consumption

- ResidualPathEnergy at k[th] hop
  - $NodeBatteryLevel_k$ (single-hop, i.e., k=1)
  - $NodeBatteryLevel_k \bullet ResidualPathEnergy_{k-1}$ (multi-hop, i.e., k>1)

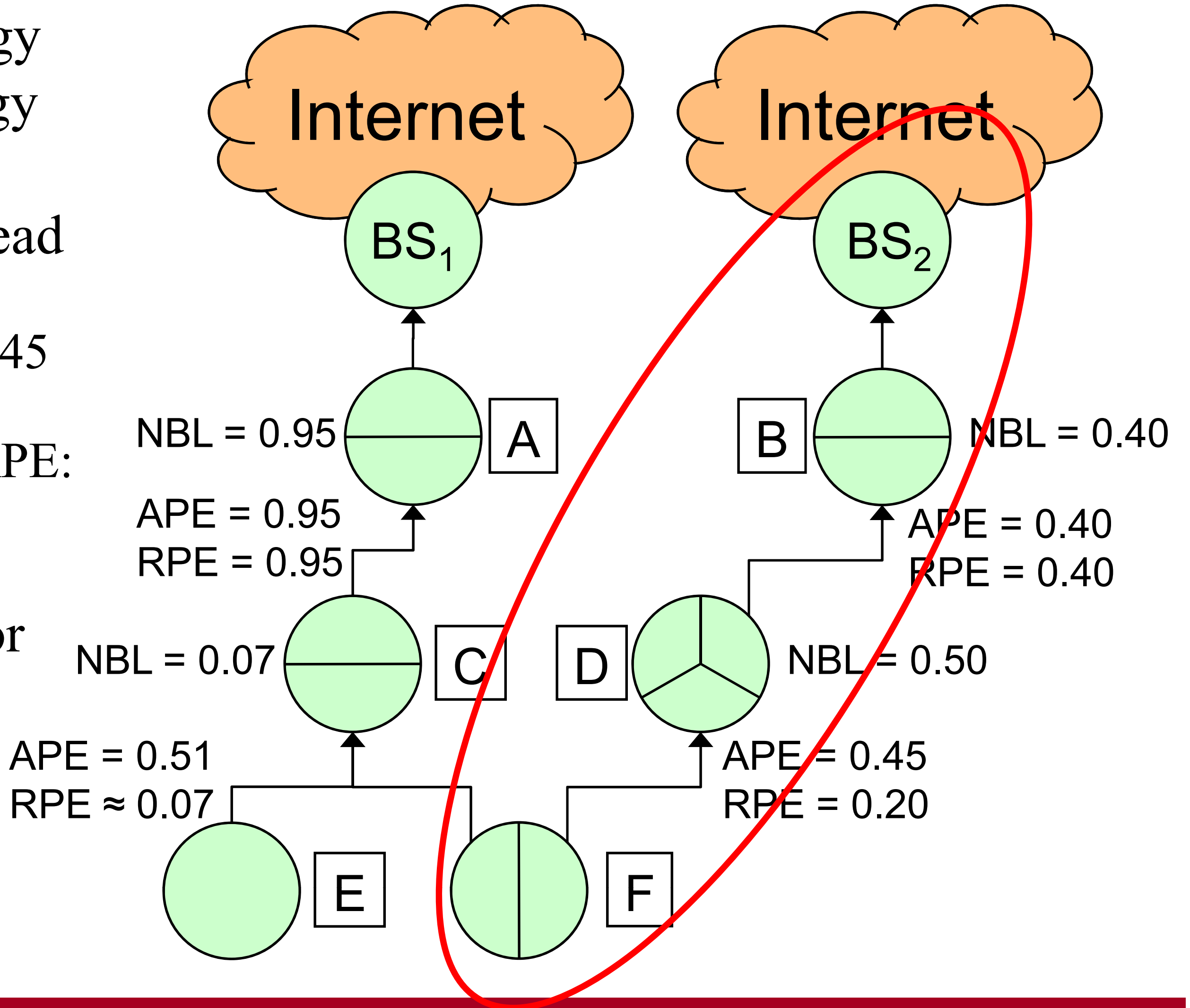
- AveragePathEnergy at k[th] hop
  - $NodeBatteryLevel_k$ (single-hop, i.e., k=1)
  - $\frac{(AveragePathEnergy_{k-1}) \cdot (k-1) + NodeBatteryLevel_k}{k}$ (multi-hop, i.e., k>1)

Energy Availability (2)

- NBL: NodeBatteryLevel
- RPE: ResidualPathEnergy
- APE: AveragePathEnergy

- **F selects BS2-B-D** instead of BS1-A-C
  - slightly lower APE: 0.45 instead of 0.51
  - but sufficiently great RPE: 0.20 instead of 0.07

- Lessons learned: push for battery level **fair exploitation**



MMHC Local Phase

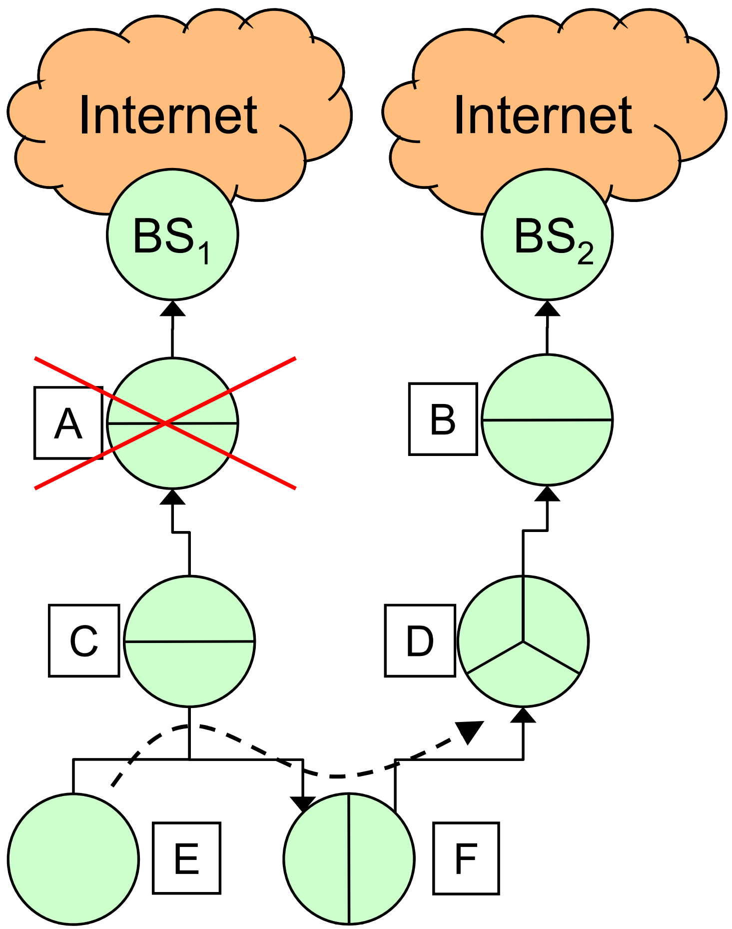
- Main goal: **quickly achieve connectivity** to the Internet
  - locally gathers RSSI and estimates CMob/Joint
  - performs **single-hop reliable connections** based on EstimatedEndurance (completely distributed evaluation)
  - select the most suitable path based on PathMobility and EstimatedThroughput (distribution of few crucial context information)
- Local phase **path selection metric**: select the path with **greatest EstimatedThroughput** but:
  - PathMobility greater than 0.8 • RequiredReliability (configurable parameter)
  - PathMobility greater than 0.5 • RequiredReliability (configurable parameter)
  - every available path
- **Reactively** activated at path disruption
- **Greater priority to connection reliability** than quality

MMHC Global Phase

- Main goal: ensure **long-term availability** enhancing connectivity capabilities
  - **periodically** interact with nearby node to **collect** PathMobility, EstimatedThroughput, AveragePathEnergy and ResidualPathEnergy
  - trigger **path modification** whenever a link is broken (reactive) or ResidualPathEnergy lowers below 0.1 (proactive)
  - **select the path** with greatest AverageBatteryEnergy, privileging paths which ResidualBatteryEnergy is in the [0.5, 1.0] range
    - avoid nodes with low battery level
    - fairly exploit available paths

- Maximize user perceived quality of service
  - available paths **periodic monitoring** and **proactive reconfiguration**
  - enhance connectivity opportunities via the **role-switch procedure**

Role-switch Procedure

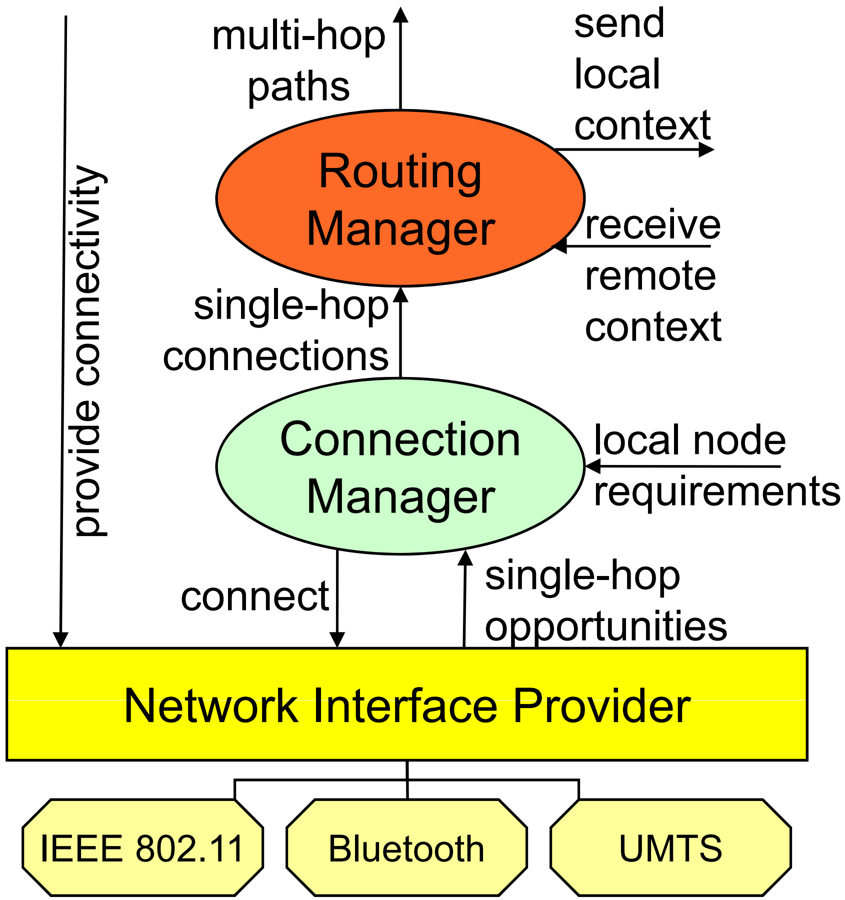


- A client can work as **bridge** among different networks
  - the **peer connector** contribute providing the **physical network**, e.g., performing as Bluetooth master
  - a **client** starts **forwarding data** via one of its available paths: it acts as a gateway

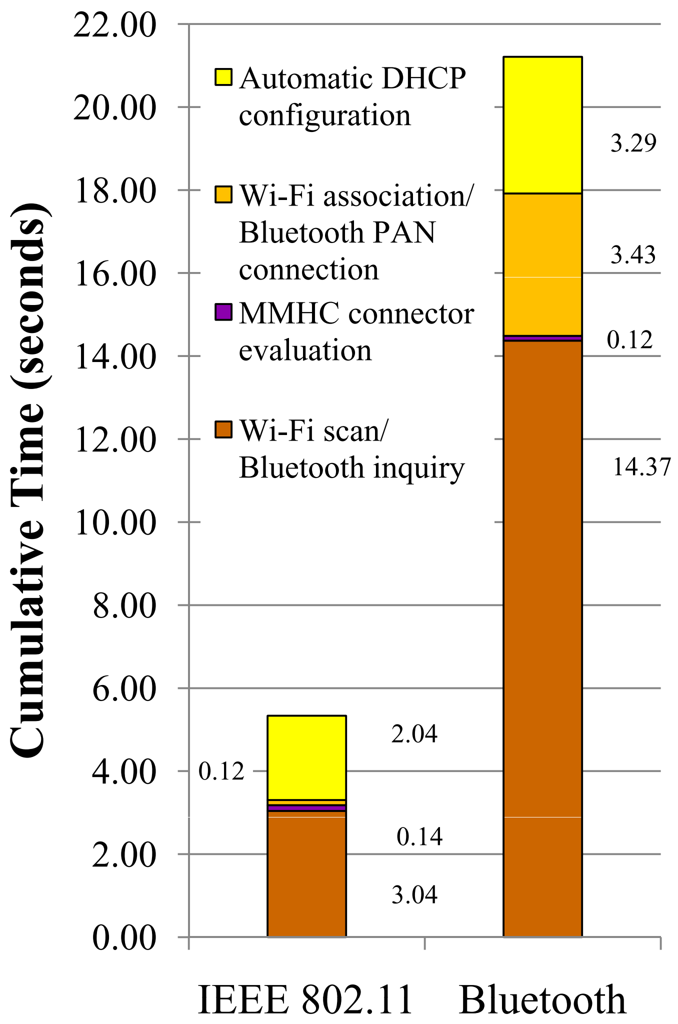
- F has two paths to the Internet
- When A fails **C exploits F as gateway**
- Both C and E keep connectivity to the Internet via F

MMHC Architecture

- Network Interface Provider
  - **homogeneous access to heterogeneous interfaces** on different operating systems
  - e.g., Linux Wireless Extensions on Linux and NDIS drivers on Windows
- Connection Manager
  - **single-hop connections** based on node mobility and path throughput
- Routing Manager
  - context information **remote distribution**
  - **multi-hop paths** managing routing rules and performing role-switch procedures

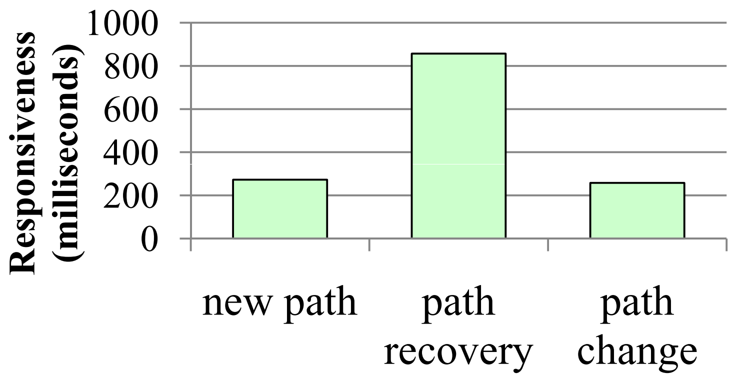


MMHC Performance Results



Connector Manager

- **Time consuming single-hop** creation and **efficient path reconfiguration**
  - reactive local phase and proactive global phase
- **MMHC overhead is negligible**
  - connection establishment delay mainly due to specific characteristics of wireless technologies



Routing Manager

Conclusions & Ongoing Work

- MMHC proposes **innovative context data** suitable for heterogeneous wireless scenarios
  - node mobility, path throughput, energy availability
- MMHC main goal is to provide **reliable connections** in wireless mobile environments
  - great throughput as secondary objective
- Two-phase approach:
  - **reactive** local management for **connectivity establishment**
  - **proactive** global management for **connectivity enhancement**

- 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/research/**MMHC**/
  - http://lia.deis.unibo.it/Staff/CarloGiannelli/