Middleware Solutions for Self-organizing Multi-hop Multi-path Internet Connectivity Based on Bluetooth

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Agenda

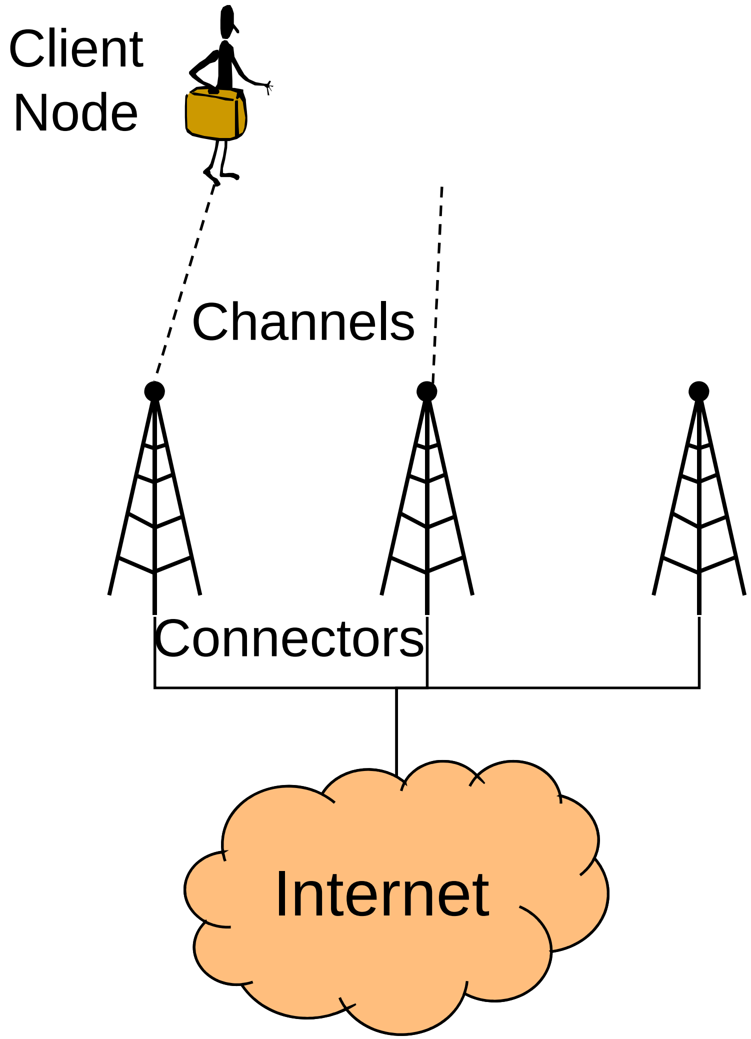
- From traditional homogeneous to novel **heterogeneous** wireless scenarios
  - several communication technologies
  - infrastructure and **peer** points of access

- **Multi-hop Multi-path Heterogeneous Connectivity (MMHC)** middleware for **context-aware** dynamic connectivity in **heterogeneous environments**
  - context information related to path reliability and throughput
  - manage interface, platform, driver **heterogeneity**
  - **efficiency required** to gather context information, evaluate connectivity opportunities, and perform connections

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., Bluetooth pairing 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?



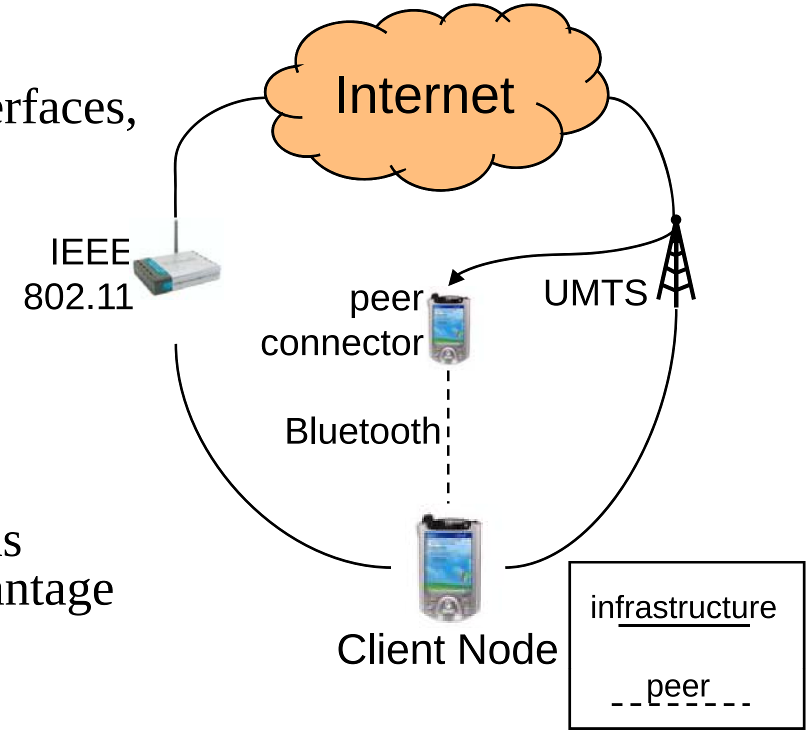
Homogeneous Wireless Scenario

- **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 (APs)
  - 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**
  - **infrastructure** or **peer** nodes
  - fixed or **mobile** peers
  - 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

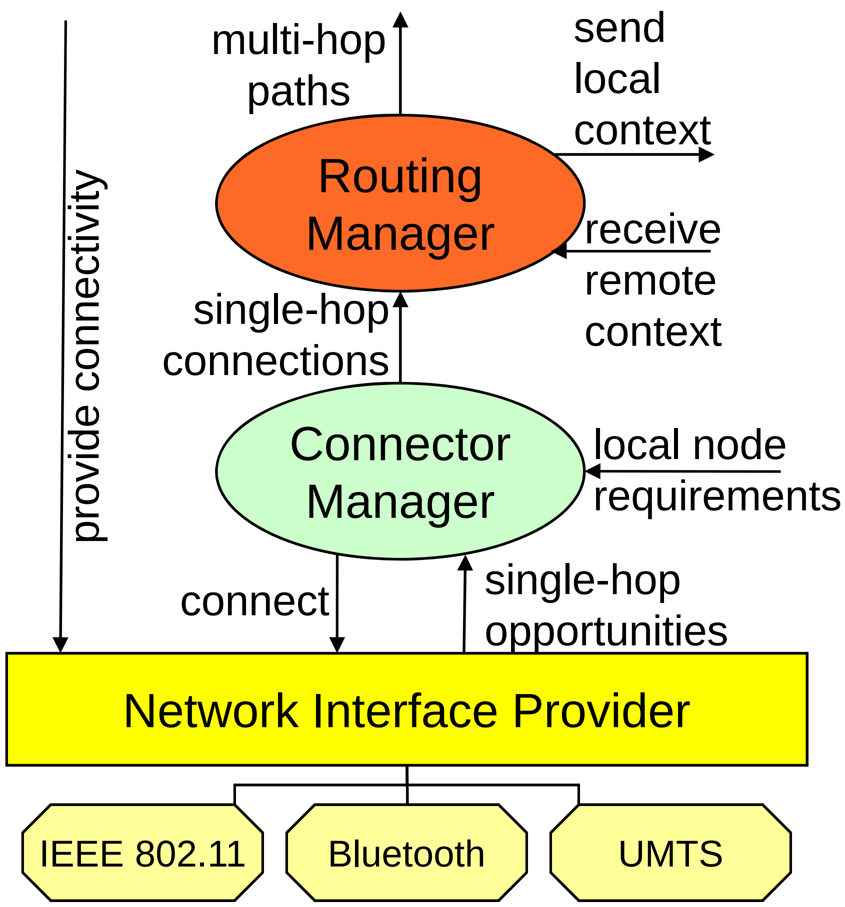
MMHC: Multi-hop Multi-path Heterogeneous Connectivity

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

- **Evaluation metric** specifically designed for heterogeneous wireless scenarios
  - client node and peer **mobility** (based on RSSI) 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**

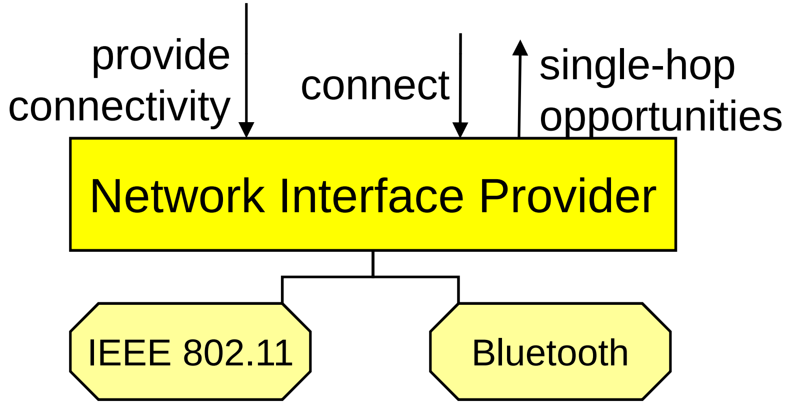
MMHC Architecture

- Network Interface Provider
  - **homogeneous access to heterogeneous interfaces** on different operating systems
- Connector Manager
  - **single-hop connections** based on node mobility
- Routing Manager
  - context information **remote distribution**
  - **multi-hop paths** based on estimated connectivity availability and throughput



Network Interface Provider

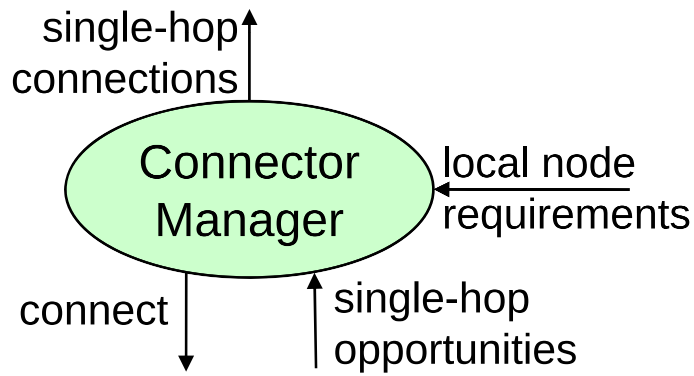
- Network Interface Provider (NIP) provides a homogeneous access to heterogeneous interfaces
- **Features**: set of capabilities common to interfaces
  - **get available connectors**, to get available connectors list and related information such as RSSI
  - **perform as peer connector**, to offer connectivity in a peer-to-peer fashion
  - **connect to a connector**, to perform a connection with a given connector
- IEEE 802.11 standard
  - **scan** of available ESSID (Extended Service Set ID)
  - connectivity provisioning via **IBSS** (Independent Basic Service Set)
  - **association** to a given AP



Connector Manager

- Connector Manager (CM) establishes **single-hop channels** with remote devices
  1) connectors discovery via **any interface**
  2) **connectors evaluation** based on **mobility degree**
  3) requires **layer2 connections** with most suitable connector of each interface
  4) activates layer3 configuration via **DHCP client**

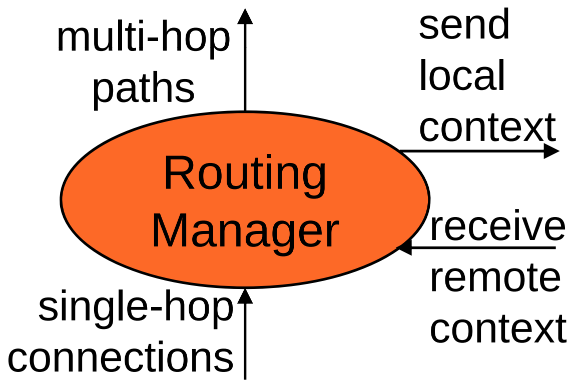
- CM does not interact with remote nodes
  - mobility degree achieved **locally** in a lightweight manner
  - requirements in terms of maximum node-connector mutual mobility



Routing Manager

- Routing Manager (RM) handles **multi-hop paths**
  1) **context information exchange** with one-hop distant nodes
  2) single-hop distant **links evaluation**
  3) **routing rule modification** to provide suitable multi-hop paths

- RM has a **wider perspective**
  - mobility, throughput and energy of paths
  - **discard unreliable paths** due to mobility, then achieve a trade-off among **throughput and energy**



Performance Considerations (1)

- Operating system and wireless interface **independent** tasks
  - **little impact** on achieved performance
  - e.g., CM spends about 120ms for the dynamic evaluation of 5 connectors
- **Operating system dependent** tasks
  - **different implementations** on different platforms
  - e.g., RM performs multi-hop path creation via `iptables` on Linux and `route` on MS Windows

Performance Considerations (2)

- **Wireless interface dependent** tasks
  - **different implementations** on different platforms and different drivers
    - IEEE 802.11: Wireless Extensions on Linux, NDIS drivers on Windows XP/Vista
    - Bluetooth: BlueZ on Linux, Widcomm , BlueSoleil and Microsoft Bluetooth Stack on Windows XP/Vista
  - great **impact on performance**
    - IEEE 802.11 AP scan and association last about 1-3s, in relation to underlying devices
    - Bluetooth inquiry procedure and pairing last more than 12s

MMHC Scenarios and Bluetooth

- Bluetooth usually exploited only to connect remote devices, e.g., wireless keyboard/mouse
  - manual connection via platform specific user interfaces
  - relatively long pairing procedure
  - limited coverage range

- Bluetooth suitable also for **connectivity provisioning**
  - much **lower power consumption** than IEEE 802.11
    - 1-35 mA instead of 100-350 mA
  - **sufficient bandwidth** for many applications
    - 0.7 Mbps for Bluetooth 1.2, 3 Mbps for Bluetooth 2.0 EDR

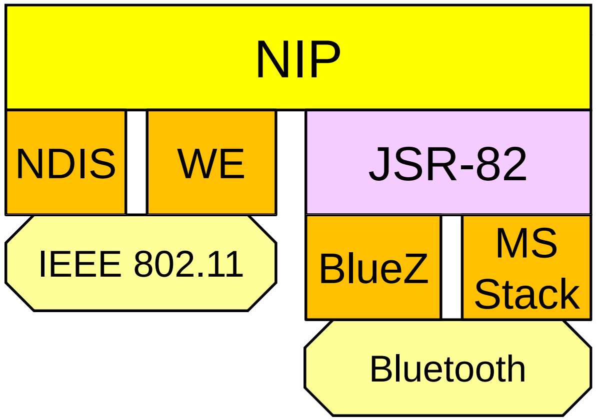
NIP and Bluetooth

- NIP implementation for Bluetooth
  - get available connectors, **inquiry procedure** to discover Bluetooth devices
  - perform as peer connector, **PAN** (Personal Area Network) provisioning and **DHCP server** instantiation
  - connect to a connector, **PAN** connection and **DHCP client**
- Bluetooth-specific issues:
  - manage driver **heterogeneity**
  - increase inquiry **efficiency**
- JSR-82 exploitation to provide a **platform independent efficient implementation** of NIP features for Bluetooth devices

JSR-82: Java APIs for Bluetooth

- Pros
  - **multi-platform** standard
  - applications can **reduce the inquiry period**
- Cons
  - do **not provide RSSI** values, required to evaluate connectors mobility
  - do **not support BNEP** (Bluetooth Networking Encapsulation Protocol), required to easily provide IP-based PAN connectivity

- Note: NIP and JSR-82 act at different layers
  - **NIP** provides homogeneous access to **heterogeneous interfaces**, e.g., IEEE 802.11 and Bluetooth
  - **JSR-82** provides homogeneous access to **heterogeneous drivers** for Bluetooth, e.g., BlueZ and MS Bluetooth Stack



Adaptable Inquiry Procedure

- JSR-82 `DiscoveryAgent` class: `startInquiry` and `cancelInquiry` methods
  - full inquiry procedure of 10.24s discovers 100% devices
  - **halved inquiry** procedure of 5.12s discovers **99% devices** [Peterson et al.]

- Connector Manager (CM) modifies inquiry procedure length in relation to the current context
  - **short inquiry** at system startup and at **connectivity disruption**
  - full inquiry otherwise

JSR-82 Extension for RSSI Gathering

- Bluetooth provides RSSI only of connected devices
  1) inquiry procedure to discover devices
  2) **baseband connection**
  3) RSSI gathering

- Linux BlueZ
  - `hcitool -i hciX` **`cc`** `remote_addr`
  - `hcitool -i hciX` **`rssi`** `remote_addr`
- Windows Widcomm
  - `BOND_RETURN_CODE` **`Bond`**`(BD_ADDR bda, BT_CHAR *pin_code)`
  - `BOOL` **`GetConnectionStats`**`(BD_ADDR bda, tBT_CONN_STATS *p_conn_stats)`

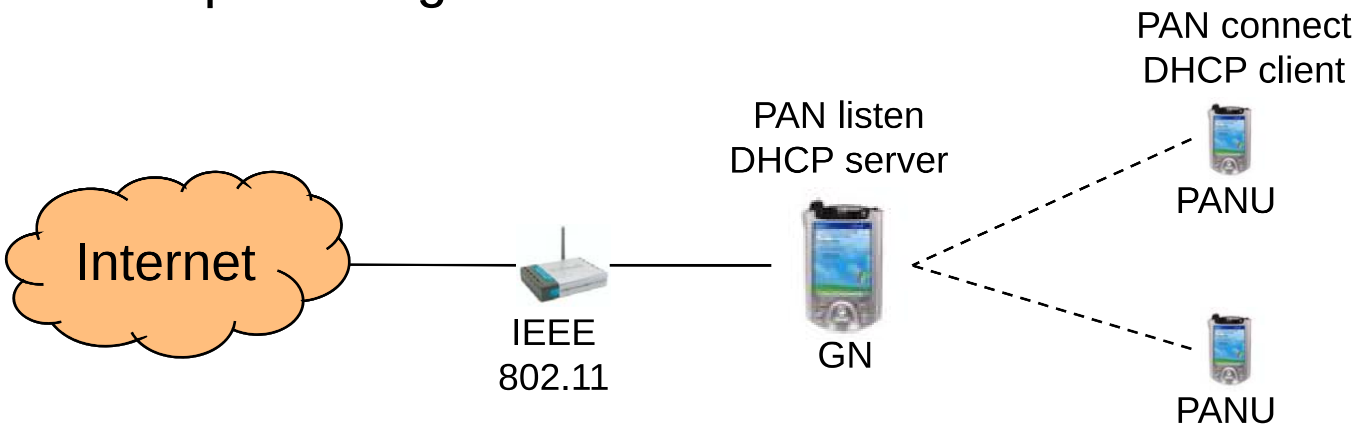
JSR-82 Extension for Connectivity Provisioning (1)

- additional `BNEPConnector` class: `server()` method
  - setup a Group Ad-hoc Network (GN) PAN: a device behaves as gateway, the others as clients
  - instantiate a DHCP server: the node acts as gateway
- Linux BlueZ
  - `pand -i hciX` **`--listen --role GN`** `--devup ./devup.sh --master`
  - `devup.sh` instantiates the **DHCP server** at connection establishment, as soon as `bnepX` interface is available
- Windows Widcomm
  - no PAN setup, no DHCP server command (available on MS Windows Server 2008)

JSR-82 Extension for Connectivity Provisioning (2)

1) NIP exploits `BNEPConnector.client(remote_addr)` to connect to a GN PAN as PANU (PAN User)
   - Linux BlueZ: `pand -i hciX` **`--connect remote_addr --role PANU`** `--service GN`
   - Windows Widcomm: **`CreateConnection`**`(remote_addr, SERVCLASS_GN)`

2) Then NIP activates a DHCP client
   - Linux: `dhclient` on `bnepX` interface
   - Windows: `ipconfig /renew *`



Conclusions & Ongoing Work

- MMHC supports **multi-hop multi-path** spontaneous connectivity exploiting off-the-shelf **heterogeneous equipment**
  - IEEE 802.11, Bluetooth, Ethernet
- Bluetooth effective exploitation via
  - **efficient inquiry** procedure to discover devices
  - **homogeneous access** to heterogeneous drivers
- **JSR-82 enhancement** to
  - **gather RSSI**, required to estimate node mobility
  - **provide BNEP** connections, to easily support IP connectivity

- Ongoing work
  - additional efforts to fully support MS Windows drivers
  - **QoS** issues: multi-hop connectivity **starvation avoidance** via dynamic and context-aware bandwidth reservation
  - **security** issues: peer mutual authentication, user incentives, dynamic level of trust management

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/