Social Sharing of Connectivity Resources: Control and Encouragement of Unselfishness in Mobile Environments

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From traditional homogeneous to novel heterogeneous wireless scenarios based on node cooperation
- several communication technologies
- infrastructure and peer points of access
- Internet connectivity sharing and peer-to-peer service provisioning

**Multi-hop Multi-path Heterogeneous Connectivity (MMHC) middleware for context-aware dynamic connectivity in heterogeneous environments**
- context information: node mobility, path throughput, energy availability
- push for social sharing of connectivity resources
  - provide connectivity effectively
  - support fairness in resource exploitation
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?
Traditional 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
Cooperative 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**

- Heterogeneity and **node cooperation 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 connector **cooperation extends connectivity** opportunities via multi-hop **paths**
    - UMTS link accessed via Bluetooth through a peer connector
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
Social Sharing of Connectivity Resources

- Users are generally **willing to collaborate**
- Specific topologies and traffic patterns may dramatically **reduce** actual **performance**

- **Effective** connectivity support
  - **avoidance of starvation** suffered by nodes distant from the wired Internet

- **Fair** sharing of connectivity resources
  - **not harming peer connectors** due to traversing traffic overload
  - **bandwidth** of clients in relation to their **behavior**: push for cooperative behavior
Maximum throughput in multi-hop paths depends on wireless technology, number of hops and number of clients.
- Clients of the same connector achieve almost the same bandwidth despite their actual behavior.
- Estimated Throughput (ET) to compare available paths.

Possible starvation in case of concurrent requests of intermediate connectors.
- Most bandwidth to the nodes closest to the wired Internet.

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Social sharing demands for both connectivity **effectiveness** and **fairness**
- lightweight solution, even if with lower accuracy

**Monitoring** of context information
- actively **discriminate** among selfish and cooperative nodes
- identify possible **starvation**

**Active control** of node behavior
- **share the load**: avoid overloading peer connectors with traversing traffic
- **reward cooperative nodes**: clients behaving as peer connectors should be rewarded with larger bandwidth
Fairness Management in MMHC Environment

- **Current Scenario**
  - top-down context information
  - bottom-up Internet connectivity

- **Social Scenario**
  - time/hop-bounded peer-to-peer service discovery/invocation
  - runtime monitoring of achieved performance
  - bottom-up starvation notification
  - example
    - node F accesses BS₂
    - node D saturates bandwidth
    - node F notifies the misbehavior
    - node D reserves some bandwidth to node F

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Local monitoring to estimate node behavior
- periodic gathering of network statistics, such as locally generated packets, traversing packets, failed outgoing packets

Context information to one-hop neighbors
- Possible Local Starvation (PLS) state on a peer connector whenever there is no traversing traffic
- Remote Starvation (RS) event sent to one-hop-distant peer connectors whenever most of the client outgoing packets fails
Three different conditions

1) **only PLS**: notification to the user of possible misbehavior, eventually ignoring the notification

2) **only RS**: RS event *propagated to upper nodes*, since client starvation not performed by the local peer connector

3) **PLS + RS**: Local Starvation (LS) event requiring to *modify local bandwidth reservation policy*
   - *favor traversing* traffic instead of locally generated one
   - *favor* most *cooperative* clients
- 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
- **Traffic Marker**
  - marks and monitors locally generated and traversing packets
  - Traversing Load, TL: traversing and local packets ratio
  - Output Effectiveness, OE: correctly sent and generated local packets

- **Starvation Monitor**
  - rises (lowers) PLS state if TL<0.05 (>0.25)
  - triggers RS event if OE<0.05
  - triggers LS event if PLS active and received RS event from a remote client

- **Traffic Controller**
  - actively manages local bandwidth reservation policy to recover from starvation
Implementation Insights

- **Traffic Marker**
  - `iptables mark` to tag traffic packets
  - **per-client tagging** exploiting input, forward and output chains of the `mangle` table

- **Starvation Monitor**
  - **regional** fairness management via **context-aware RS event propagation** (no indiscriminate multi-hop event flooding)

- **Traffic Controller**
  - `tc` command whenever a client joins/leaves the network
  - \( bw_L = ET \times (1 - RB) \) (local peer connector)
  - \( bw_{Ci} = w_{Ci} \times (ET \times RB) \) (remote clients) where \( \sum_{Ci} w_{Ci} = 1 \)
  - \( RB \) (Remote Bandwidth) at least 0.50 in case of RS event, thus **at least 50% of the bandwidth reserved to clients**
Conclusions & Ongoing Work

- MMHC supports **multi-hop multi-path** spontaneous connectivity exploiting off-the-shelf **heterogeneous equipment**
  - IEEE 802.11, Bluetooth, Ethernet

- Pushing for **social sharing of connectivity**
  - detection of and recover from **starvation**
  - **reward** cooperative nodes

- **Regional** scope
  - local and one-hop distant context-awareness
  - decentralized and lightweight solution

- **Ongoing work**
  - context-aware **peer-to-peer service** discovery and invocation
  - **security** issues: peer mutual authentication, user incentives, dynamic level of trust management

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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/