Internet Connectivity Sharing in Multi-path Spontaneous Networks: Comparing and Integrating Network- and Application-Layer Approaches

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Agenda

- **Spontaneous networking**
  - opportunities and technical challenges

- **Internet connectivity sharing**
  - *multi-hop, multi-path, heterogeneous, opportunistic*
  - layer-3 vs. layer-7 approaches

- **RAMP middleware**
  - layered architecture
  - primary middleware facilities for supporting and facilitating app development
  - preliminary experimental results
Spontaneous Networking (1)

- **Impromptu** interconnection of mobile and fixed nodes
  - *users willing to share* content and resources
- **Maximize resource/service utilization** by potentially interconnected nodes
  - *heterogeneous* wireless technologies
  - *both infrastructure and ad-hoc* connectivity
  - *multiple* connectivity opportunities
  - *sporadic/opportunistic* Internet connectivity
Node cooperation to
- provide single-hop connectivity
- manage multi-hop connectivity
- support peer-to-peer services

Peer-to-peer resource sharing
(Internet connectivity, file sharing, …)
- service advertising: NodeA provides lesson notes
- service discovery: NodeF looks for nodes that share files
- service invocation: NodeF browses and downloads notes stored on NodeA

NodeA and NodeF may reside in different layer-3 networks
Spontaneous Networking: Technical Challenges

- **Heterogeneous** nodes and connectivity
  - IEEE 802.11, Bluetooth, Ethernet
  - several operating systems
- **Decentralized and loosely-coupled** network management
  - localized provisioning of layer-2/3 connectivity
  - interconnection of *heterogeneous* layer-3 networks
- **Erratic and unpredictable behavior**
  - nodes abruptly create/destroy pieces of network
  - nodes dynamically join/move/leave

- **Scenario and management complexity** makes hard the development of novel applications from scratch => *need for middleware solutions*
Easy-to-use middleware supporting spontaneous network management, transparent in relation to
- operating systems
- wireless technologies
- layer-3 network configurations
- node mobility

Unicast and broadcast comm. support
- per-packet sendUnicast, sendBroadcast, receive

Peer-to-peer service provisioning and discovery
- per-service registerService, findService

RAMP Java prototype available on MS Windows XP/Vista/7, Linux, and Mac OS X
Layered Architecture

**Service Layer**
- high-level features for peer-to-peer service offering and discovery
- **Discovery**: mission-oriented TTL-bound broadcast
- **ServiceManager**: registration and advertising
- service invocation via Core Layer

**Core Layer**
- low-level primitives for end-to-end communication
- **E2EComm**: communication primitives for data en/decapsulation into RAMP packets
- **Heartbeater** for local IP addresses gathering and single-hop neighbors discovery
- **Dispatcher**: actual inter-node packet forwarding
- listener-based plug-in for run-time packet management
Border Nodes (BNs) with direct Internet connectivity share their access

Layer-3 (L3) approach
- operating system default gateway to create multi-hop paths
- at most one path for each node

Layer-7 (L7) approach
- packets managed and dispatched by RAMP
- simultaneous exploitation of different paths and different access
L3 and L7 approaches together
- L3: minimum routing and communication overhead, but local decisions may affect remote nodes
- L7: multi-path enabling and operating system transparent, but increased communication overhead
- multiple modes of combining L3 and L7 approaches

Context-aware path selection (see also MMHC)
- quantitative metric for dynamic path evaluation
- limited information dissemination to minimize overhead

Differentiated metrics at service initialization and provisioning time
- first, coarse-grained evaluation based on rather static context information
- then, finer-grained dynamic re-evaluation based on context related to actual run-time performance
Internet Connectivity Sharing: Application Components

- **InternetService**
  - BNs *directly connected to the Internet*
  - `registerService` to advertise Internet connectivity provisioning

- **InternetClient**
  - RAMP node requiring Internet connectivity
  - `findService` to discover BNs providing connectivity

- **Layer3Manager**
  - *layer-3 gateway modification*
  - Dispatcher listener monitoring traversing packets on intermediary nodes
L3SP Mode: Layer-3 Single Path

Collaboration of intermediary nodes
- request forwarding from client to BN
- *dynamic modification of local default gateway*

Layer3Manager
- monitor traversing packets and recognize modification requests
- e.g., in Linux `route` and `iptables` commands
Data to/from the Internet *encapsulated into RAMP packets at app layer* and forwarded via Dispatcher

*Double proxy architecture*
- InternetClient/Service act as *proxies*
- e.g., HTTP proxy server on clients and BNs, en/decapsulating HTTP requests and responses

*Multi-path connectivity*
- *increased overall bandwidth*
- *greater reliability*
- Both L3 and L7 approaches

**InternetClient selects the most proper mode at runtime**
- one L3 path + multiple L7 paths
- double-proxy in case of L7 approach
- single-proxy in case of L3 approach (no InternetService)
L3SP, L7MP, and L3L7CMP: a Comparison

- **L3SP mode**
  - provides direct access to the Internet with *no additional overhead*
  - but *path modification requests may affect other nodes*

- **L7MP mode**
  - *no need of path pre-configuration*
  - but *double-proxy en/decapsulation overhead* (only HTTP at the moment)

- **L3L7CMP mode**
  - suitable for dynamic environments (as L7MP)
  - reduced overhead (in case of single-proxy)
Dynamic Path Selection

- **Context-aware performance monitoring/evaluation** and selection of available paths
  - dynamic weight-based exploitation of every BN
  - static and dynamic metrics

- **PathLength**
  - static comparison of path length
  
  \[
  w_i = 1 - \left( \frac{\text{path}_i \text{Length}}{\text{averageLength} / \# \text{paths}} \right) / \# \text{paths} - 1
  \]

- **PathThroughput**
  - lightweight throughput monitoring
    \[ \text{requestPayload} + \text{responsePayload} / \text{elapsedTime} \]
  - dynamic weight reconfiguration
    \[ w_i = \frac{\text{path}_i \text{Throughput}}{\text{averageThroughput} / \# \text{paths}} \]
L7MP Performance

- **Google maps browsing: HTTP intensive communication**
  - *very frequent* interactions with *limited payload size*

- Bandwidth limitation towards BNs
  - periodic *weights re-evaluation* accordingly to really achieved throughput
  - bandwidth allocation swap after 105s
L3L7CMP Performance

- Same bandwidth allocation, *both L3 and L7 approaches simultaneously*
  - L3 path towards BN₁, L7 path towards BN₂
  - Throughputs are similar, *L3 path slightly better*
  - *L7 path weight tend to be slightly lower*

- Approach swap after 125s
  - Weights change accordingly after few iterations
Conclusions and Ongoing Work

- RAMP supports *multi-hop service-oriented* communication in *heterogeneous spontaneous networks*
  - easy-to-use API for service development by non-expert programmers
- *Internet-connectivity sharing* as possible central application
  - *layer-3 and layer-7 approaches simultaneously*
  - multi-path for greater quality and reliability
  - proper path *dynamic evaluation and selection*

Ongoing work
- live multimedia stream *via DVB-T re-casting*
- porting to additional *mobile platforms*, e.g., Google Android and iPhoneOS
Any Questions?

Thanks for your attention 😊
Questions time…

Prototype code and implementation insights

- [http://lia.deis.unibo.it/research/RAMP/](http://lia.deis.unibo.it/research/RAMP/)
- [http://lia.deis.unibo.it/Staff/PaoloBellavista/](http://lia.deis.unibo.it/Staff/PaoloBellavista/)