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

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1.7.2010 - Mobilware'10

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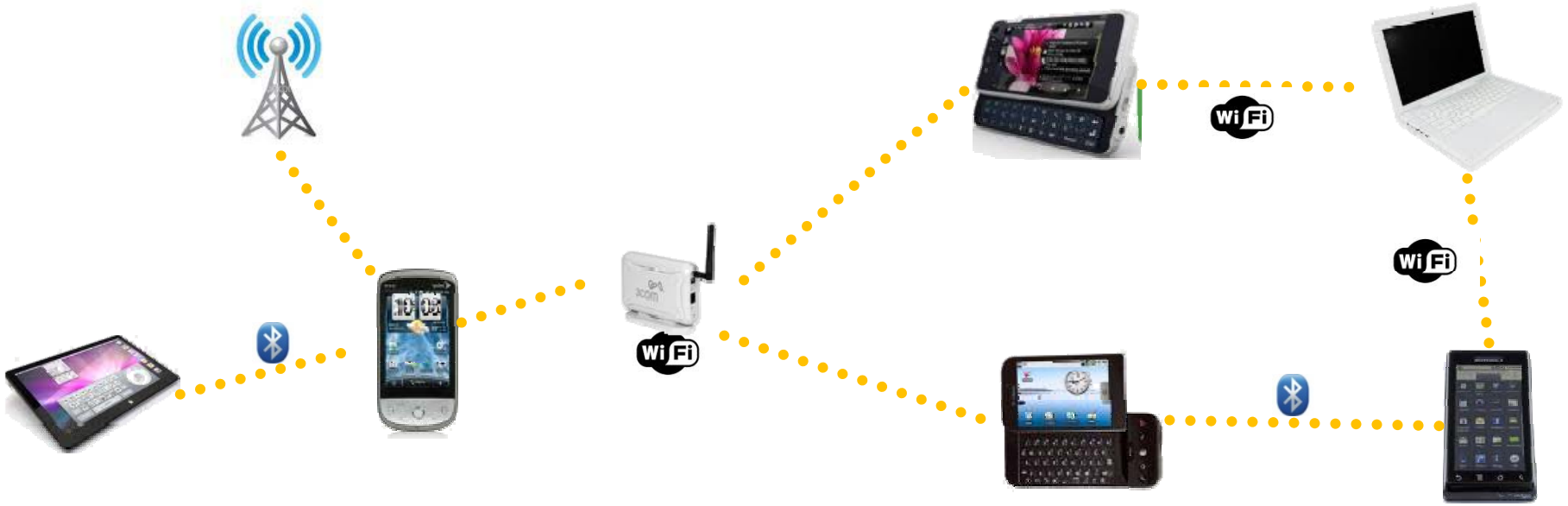
Agenda

- ***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

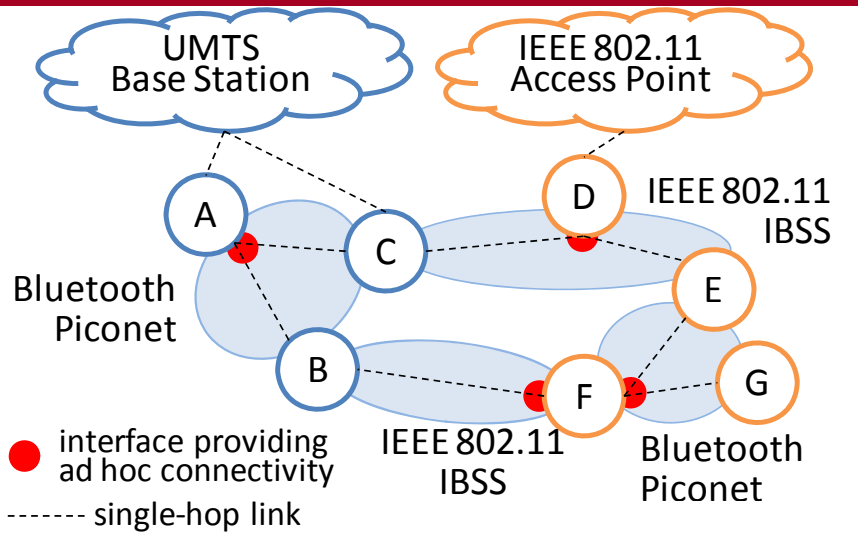
Spontaneous Networking (1)



- ***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

Spontaneous Networking (2)

- ***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***

RAMP: Real Ad-hoc Multi-hop Peer-to-peer

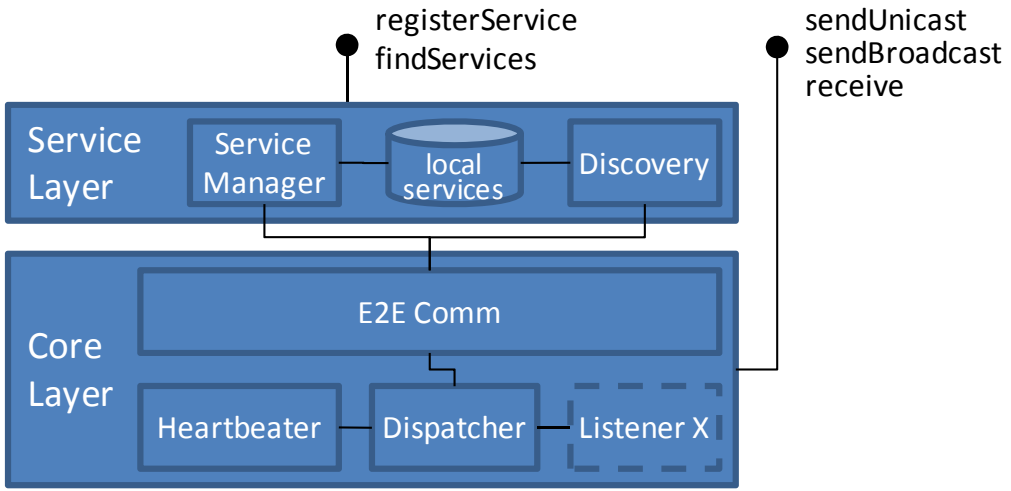
- ***Easy-to-use middleware*** supporting spontaneous network management, transparent in relation to
  - operating systems
  - wireless technologies
  - layer-3 network configurations
  - node mobility

- ***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

RAMP Layered Architecture

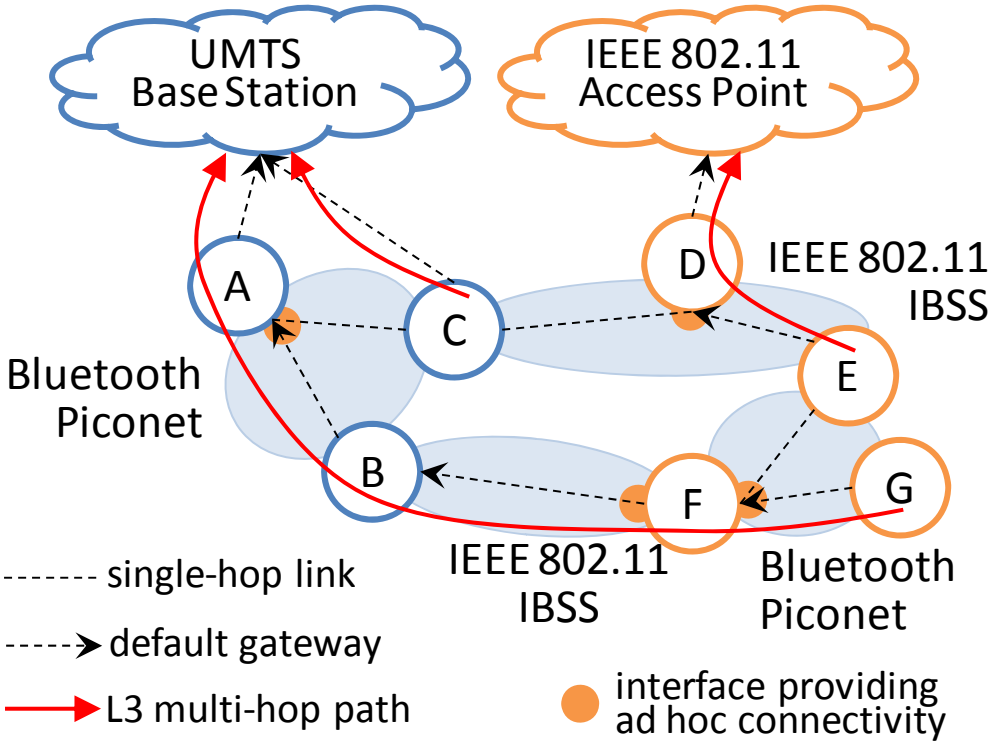
- ***Service Layer***
  - high-level features for peer-to-peer service offering and discovery
  - **Discovery**: mission-oriented TTL-bound broadcast
  - **ServiceManager**: registration and advertising
  - service invocation via Core Layer



- ***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

Internet Connectivity Sharing in Spontaneous Networks

- ***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***



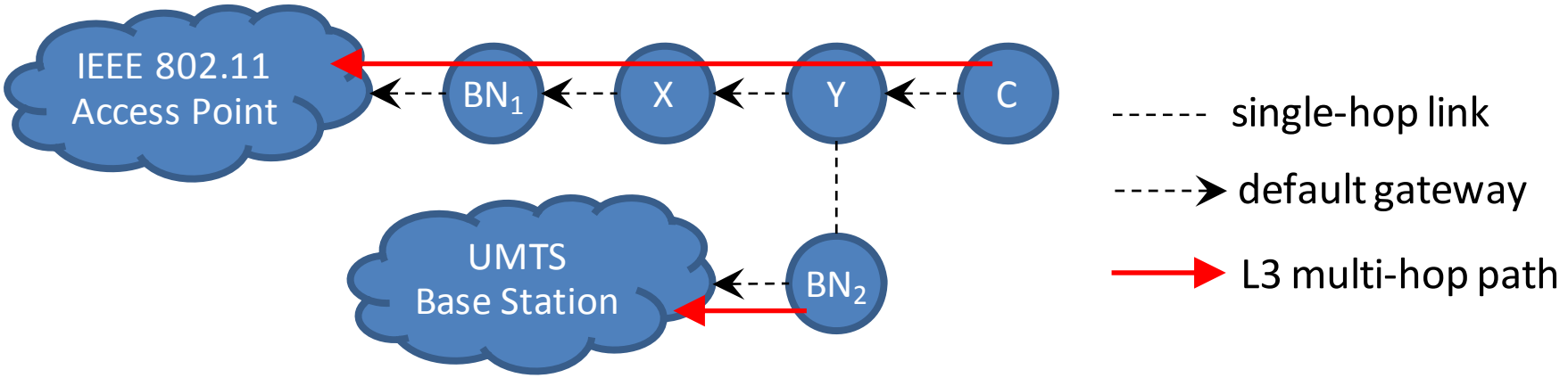
Guidelines for Internet Connectivity Sharing

- ***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

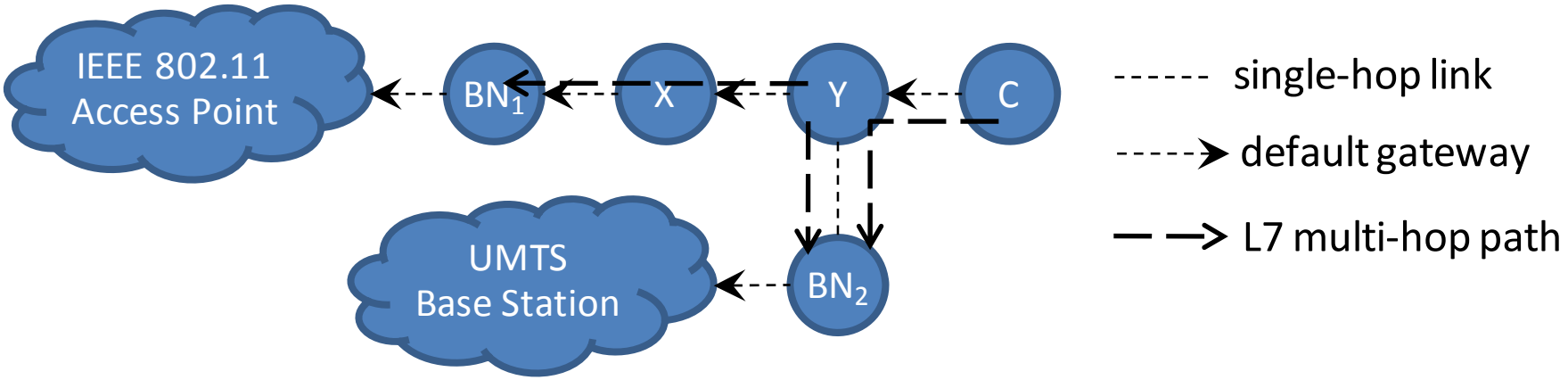
L3SP Mode: Layer-3 Single Path



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

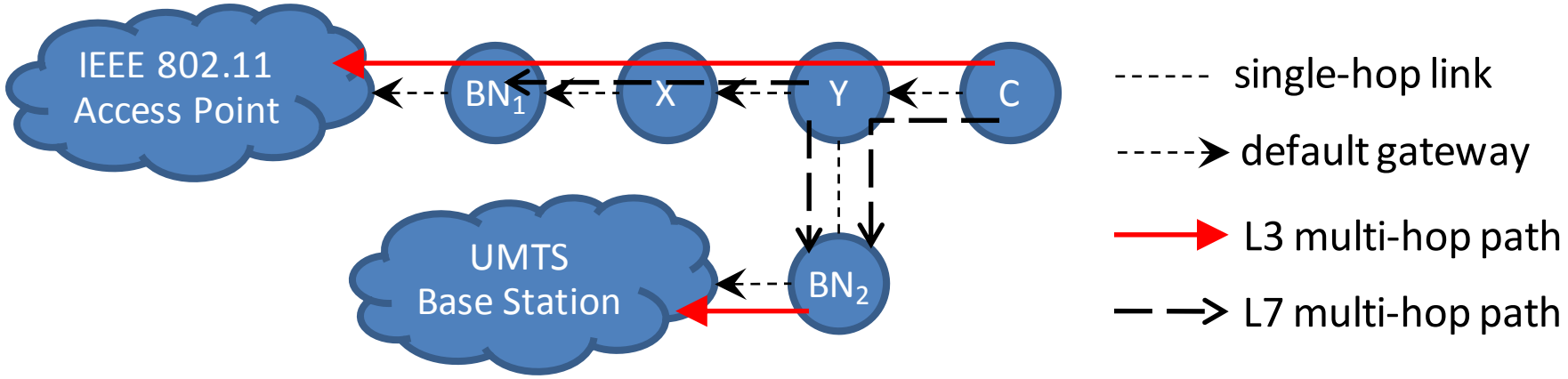
- Layer3Manager
  - monitor traversing packets and recognize modification requests
  - e.g., in Linux **`route`** and **`iptables`** commands

L7MP Mode: Layer-7 Multi Path



- Data to/from the Internet ***encapsulated into RAMP packets at app layer*** and forwarded via Dispatcher
- ***Double proxy architetcure***
  - 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***

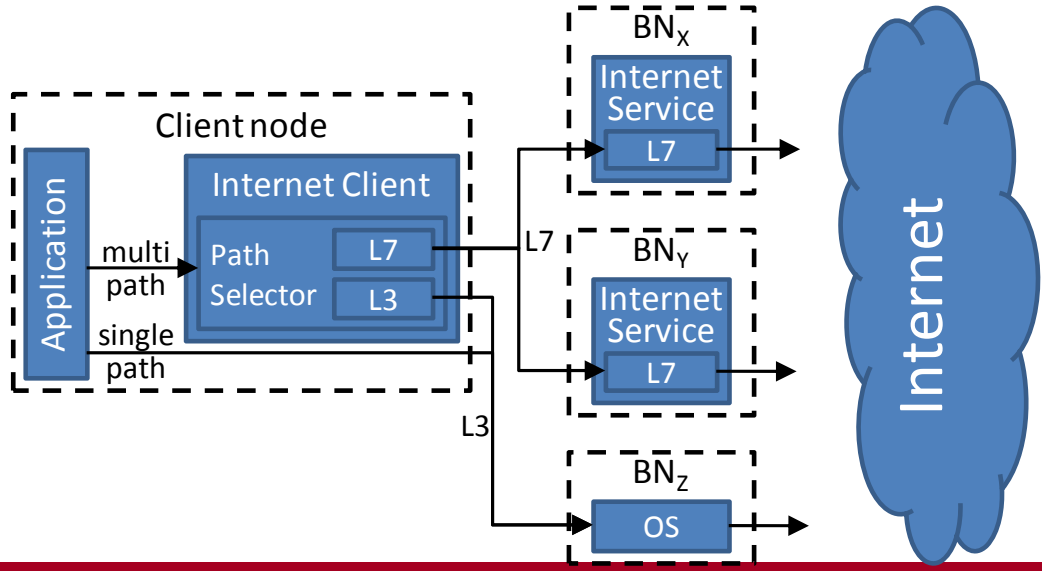
L3L7CMP Mode: L3 L7 Combo Multi Path



- 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

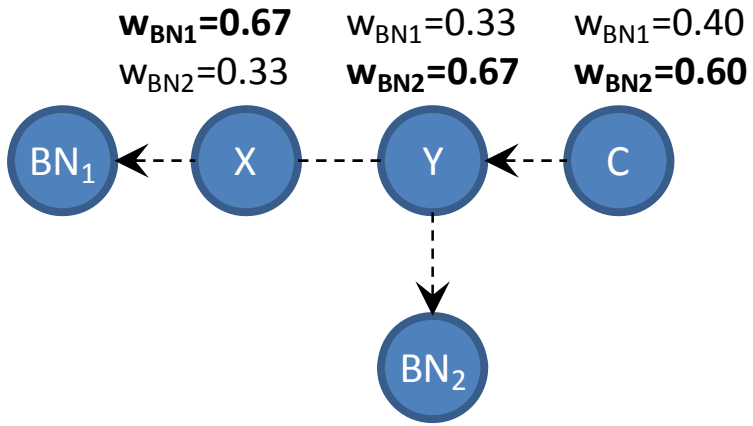
$$w_i = \frac{1 - (path_i Length \,/\, averageLength \,/\# paths)}{\# paths - 1}$$

- ***PathThroughput***
  - ***lightweight*** throughput monitoring

$$\frac{requestPayload + responsePayload}{elapsedTime}$$

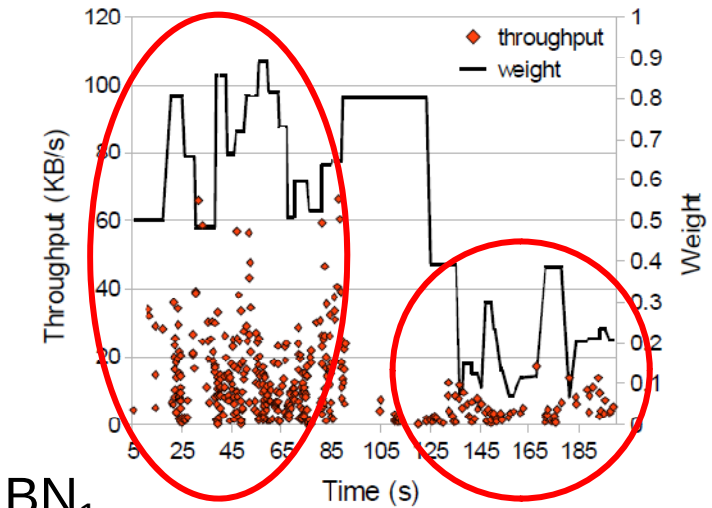
  - ***dynamic*** weight reconfiguration

$$w_i = path_i Throughput \,/\, averageThroughput \,/\# paths$$

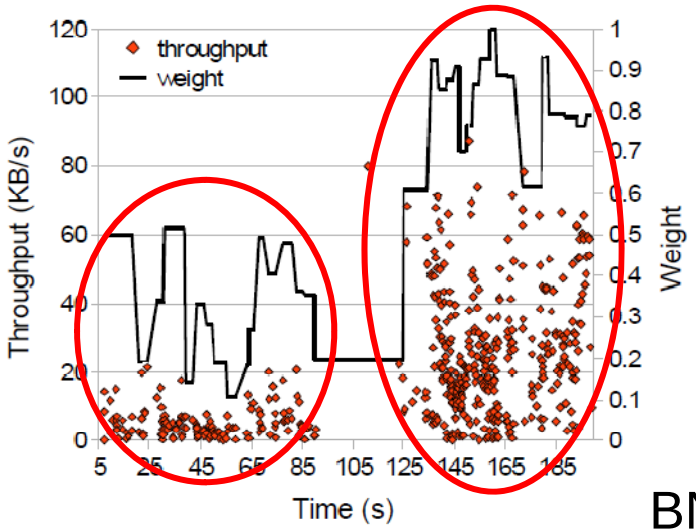


L7MP Performance

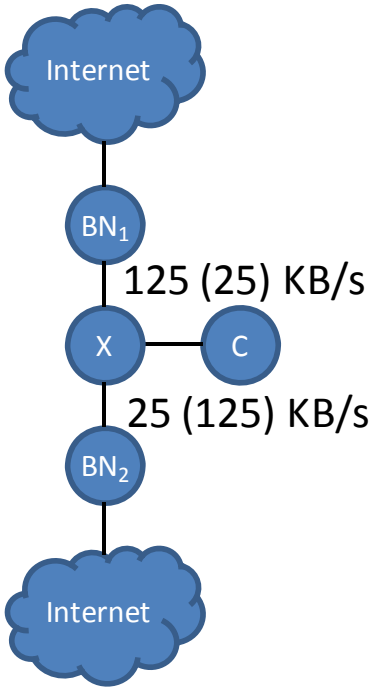
- ***Google maps browsing: HTTP intensive communication***
  - ***very frequent*** interactions with ***limited payload size***
- Bandwidth limitation towards BNs
  - periodic ***weights re-evaluation*** accordingly to really achieved throughput
  - bandwidth allocation swap after 105s



BN_1

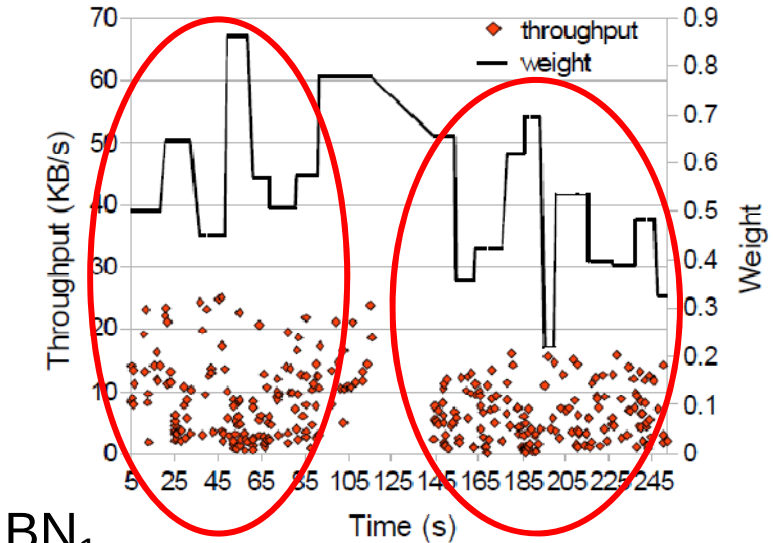


BN_2

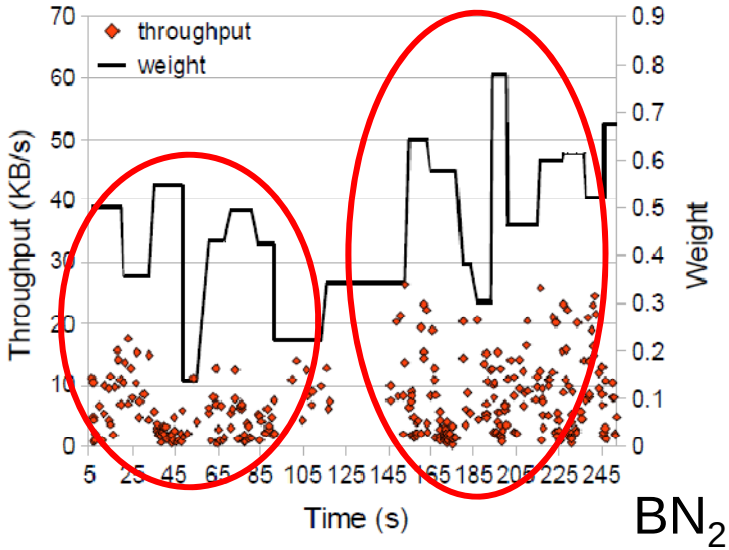


L3L7CMP Perfomance

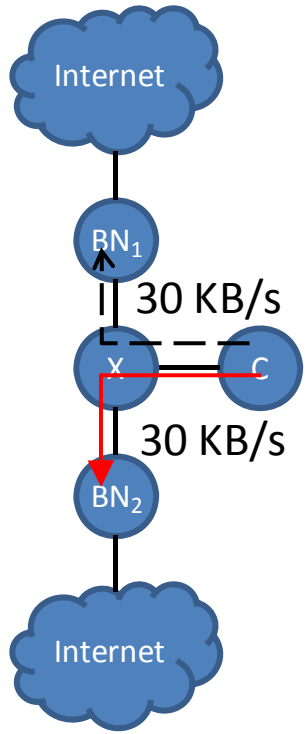
- Same bandwidth allocation, ***both L3 and L7 approaches simultaneously***
  - L3 path towards BN_1, L7 path towards BN_2
  - throughputs are similar, ***L3 path slightly better***
  - ***L7*** path weight tend to be ***slightly lower***
- Approach swap after 125s
  - weights change accordingly after few iterations



BN_1



BN_2



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/Staff/PaoloBellavista/`**