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

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- n *Spontaneous networking*
  - ❑ opportunities and technical challenges
- n *Internet connectivity sharing*
  - ❑ *multi-hop, multi-path, heterogeneous, opportunistic*
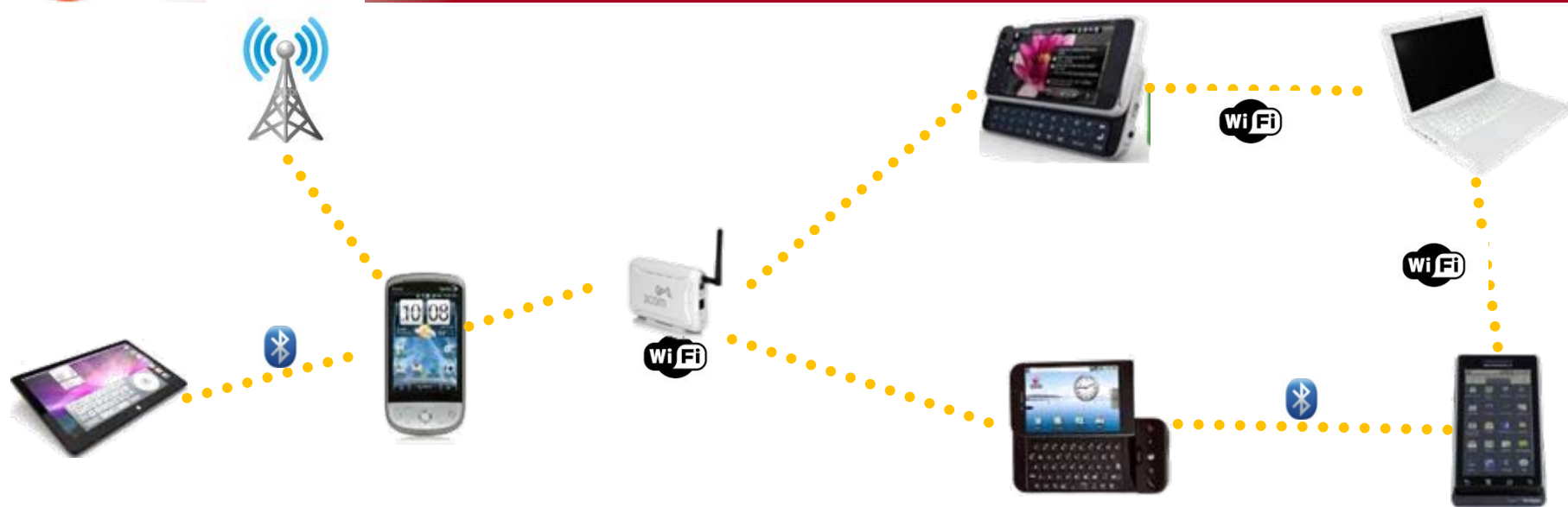 - ❑ layer-3 vs. layer-7 approaches
- n *RAMP middleware*
  - ❑ layered architecture
  - ❑ primary middleware facilities for supporting and facilitating app development
  - ❑ preliminary experimental results

- n **Impromptu** interconnection of mobile and fixed nodes
  - ❑ **users willing to share** content and resources
- n **Maximize resource/service utilization** by potentially interconnected nodes
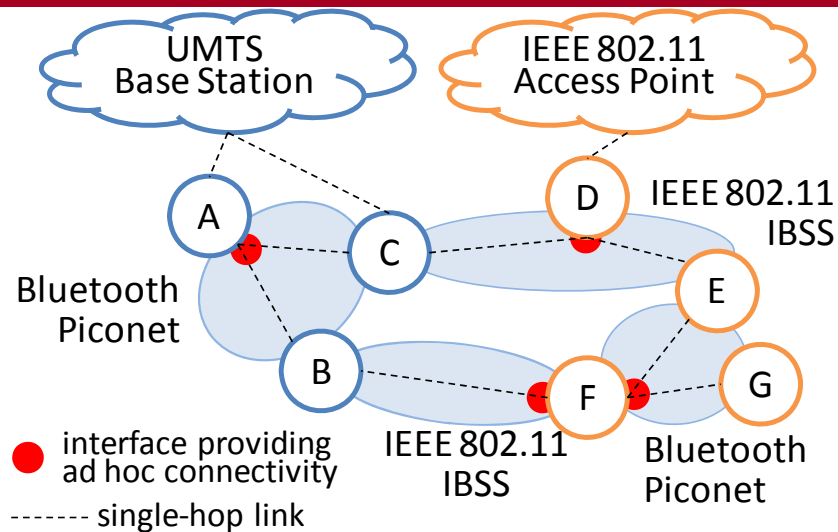 - ❑ **heterogeneous** wireless technologies
  - ❑ **both infrastructure and ad-hoc** connectivity
  - ❑ **multiple** connectivity opportunities
  - ❑ **sporadic/opportunistic** Internet connectivity

n **_Node cooperation_** to
  - ❑ provide single-hop connectivity
  - ❑ manage multi-hop connectivity
  - ❑ support peer-to-peer services

UMTS Base Station

IEEE 802.11 Access Point

D

IEEE 802.11 IBSS

A

C

E

Bluetooth Piconet

B

F

G

● interface providing ad hoc connectivity

------- single-hop link

IEEE 802.11 IBSS

Bluetooth Piconet

n 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

n NodeA and NodeF may reside in **_different layer-3 networks_**

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

- n ***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`
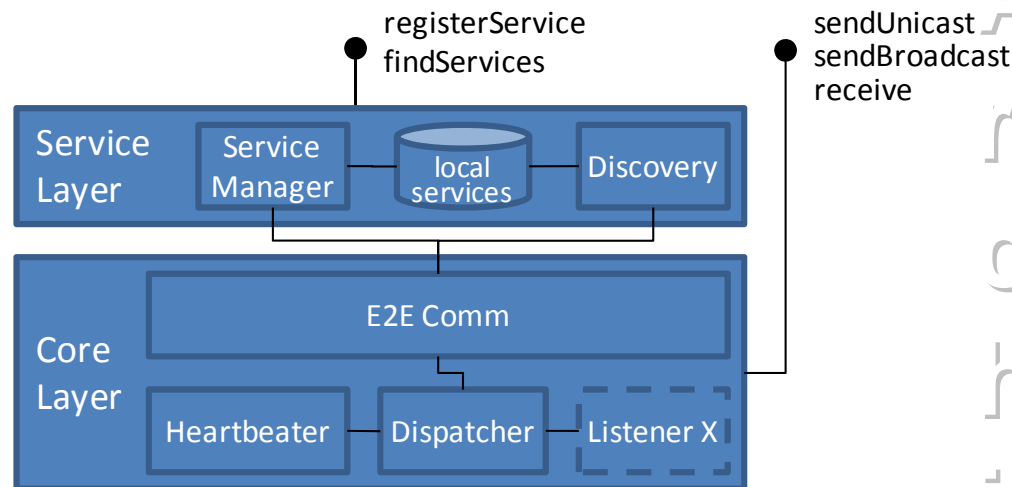
- **_Peer-to-peer service provisioning and discovery_**
  - ❑ **_per-service_** `registerService, findService`

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

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

The diagram shows registerService, findServices connecting to the Service Layer (Service Manager, local services, Discovery) and sendUnicast, sendBroadcast, receive connecting to the Core Layer (E2E Comm, Heartbeater, Dispatcher, Listener X).

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
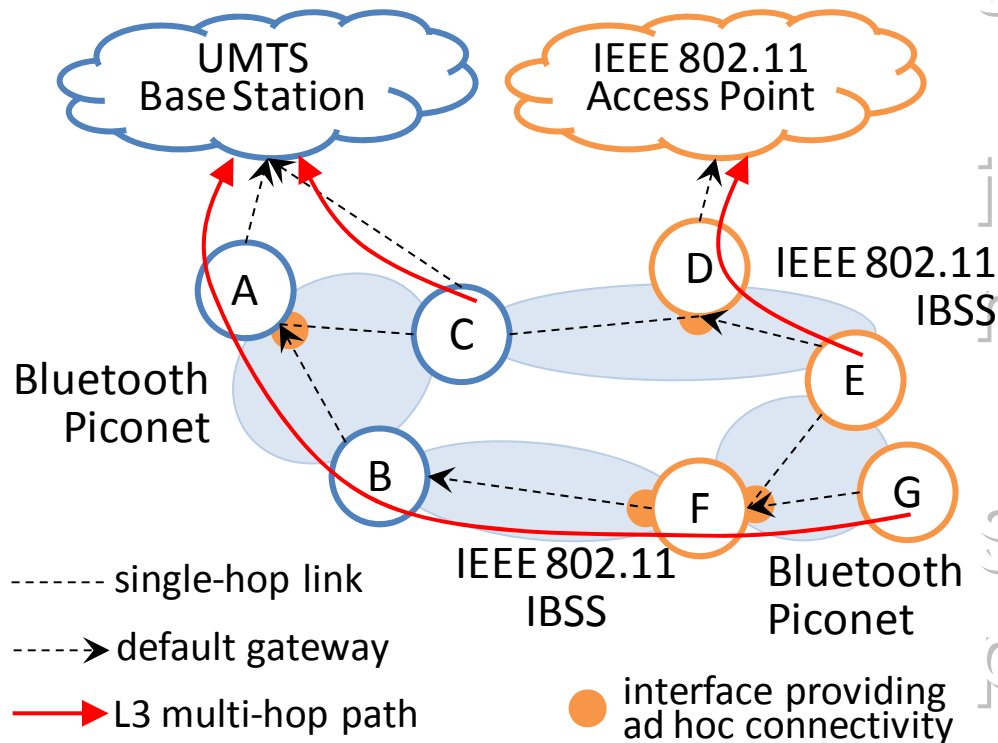- ❑ listener-based plug-in for run-time packet management

- **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**

UMTS Base Station

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Bluetooth Piconet

------- single-hop link

----→ default gateway

——→ L3 multi-hop path

● interface providing ad hoc connectivity

n **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

n **Context-aware path selection** (see also MMHC)

- ❑ quantitative metric for dynamic path evaluation
- ❑ limited information dissemination to minimize overhead

n **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
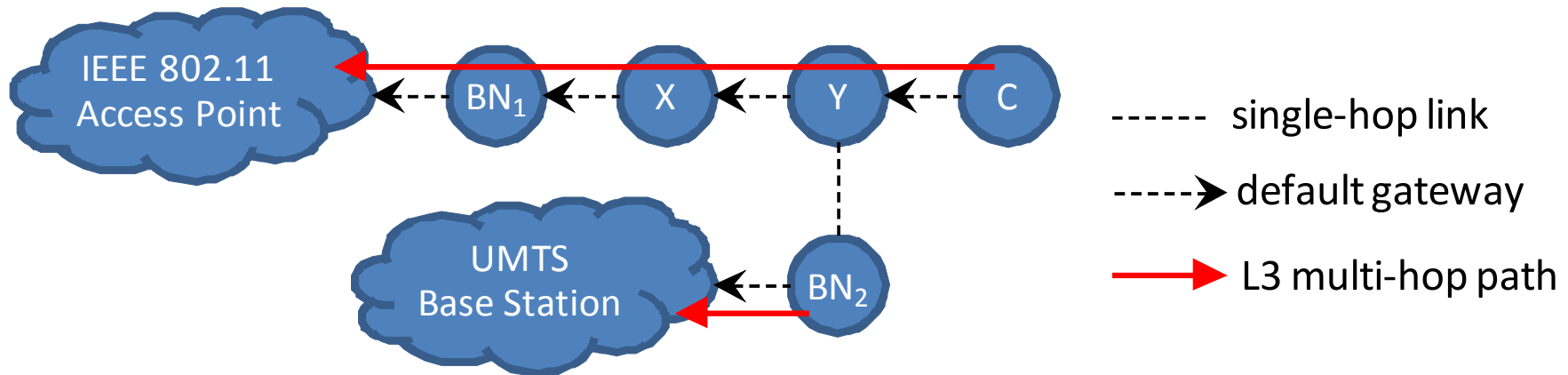
n **_InternetService_**
   - BNs **_directly connected to the Internet_**
   - **`registerService`** to advertise Internet connectivity provisioning

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

n **_Layer3Manager_**
   - **_layer-3 gateway modification_**
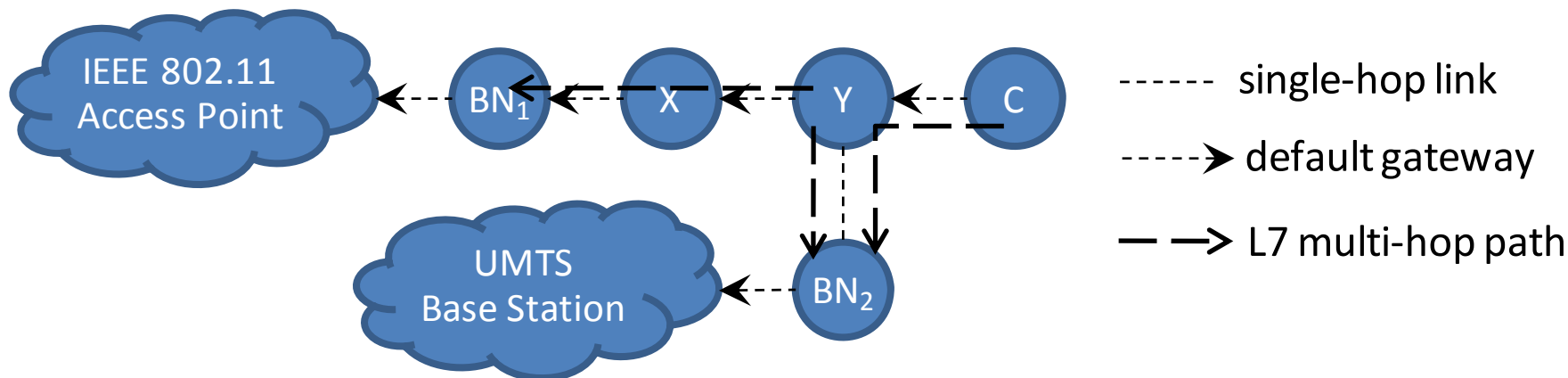   - Dispatcher listener monitoring traversing packets on intermediary nodes

IEEE 802.11 Access Point

BN$_1$ ← X ← Y ← C

UMTS Base Station

BN$_2$

------ single-hop link

-----→ default gateway

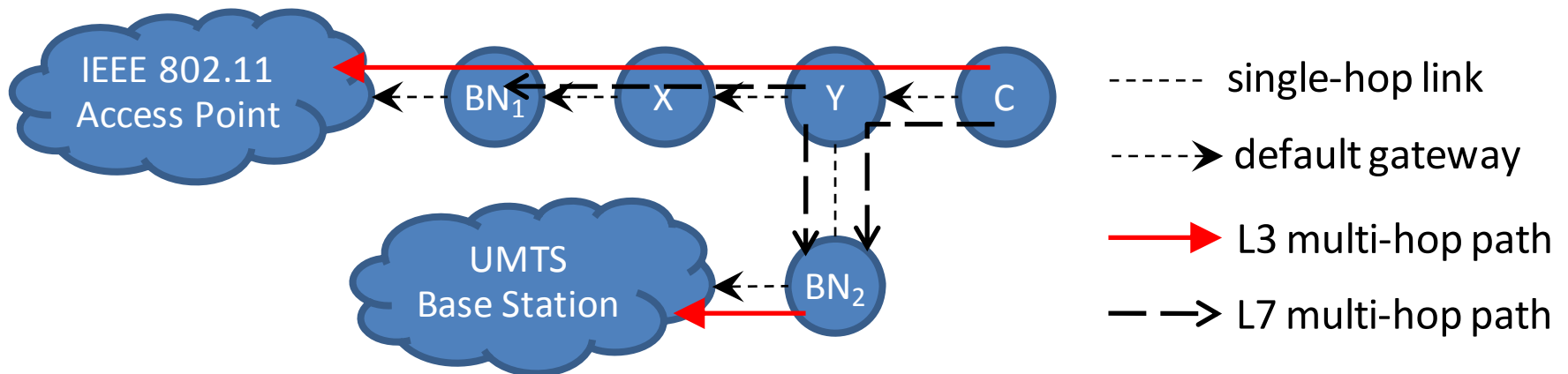→ L3 multi-hop path

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

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

IEEE 802.11 Access Point — BN$_1$ — X — Y — C

single-hop link

default gateway

L7 multi-hop path

UMTS Base Station — BN$_2$

- 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*

The diagram shows an IEEE 802.11 Access Point (cloud) and UMTS Base Station (cloud) connected to nodes BN₁, X, Y, C, and BN₂.

Legend:
- ------ single-hop link
- -----> default gateway
- (red arrow) L3 multi-hop path
- (black dashed arrow) L7 multi-hop 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 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)
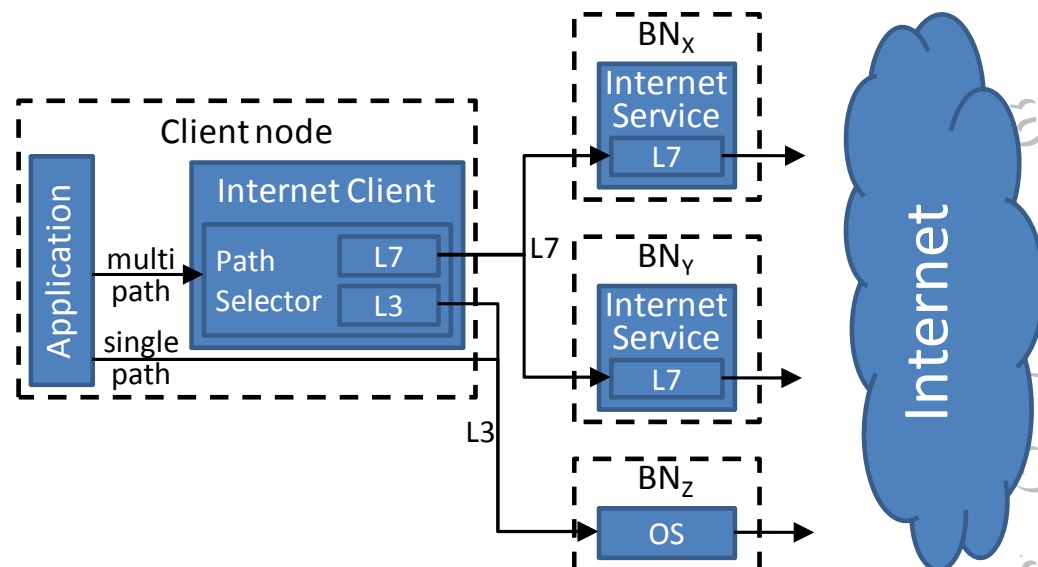
- **n** *Context-aware performance monitoring/evaluation* and selection of available paths
  - ❑ dynamic weight-based exploitation of every BN
  - ❑ *static and dynamic metrics*
- **n** *PathLength*
  - ❑ *static* comparison of path length

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

- **n** *PathThroughput*
  - ❑ *lightweight* throughput monitoring

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

  - ❑ *dynamic* weight reconfiguration

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

$w_{BN1}=0.67$ $w_{BN1}=0.33$ $w_{BN1}=0.40$
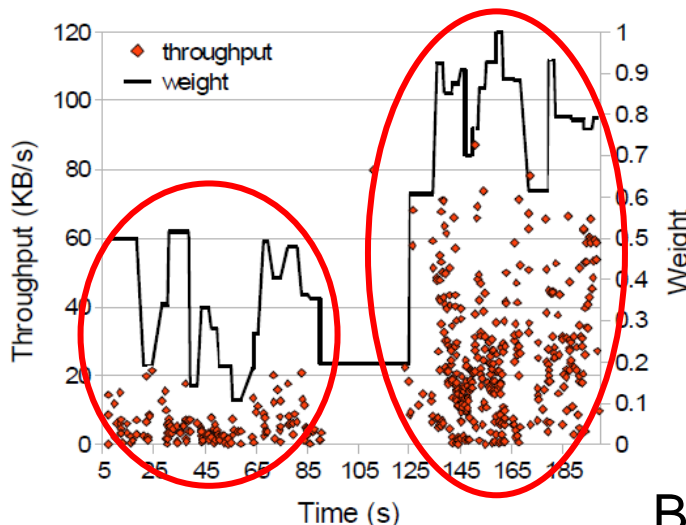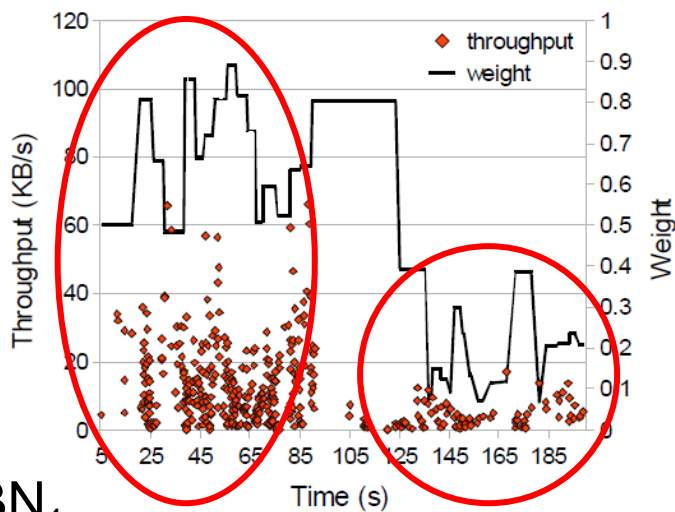$w_{BN2}=0.33$ $w_{BN2}=0.67$ $w_{BN2}=0.60$

BN₁ ⬅ X ⬅ Y ⬅ C

BN₂
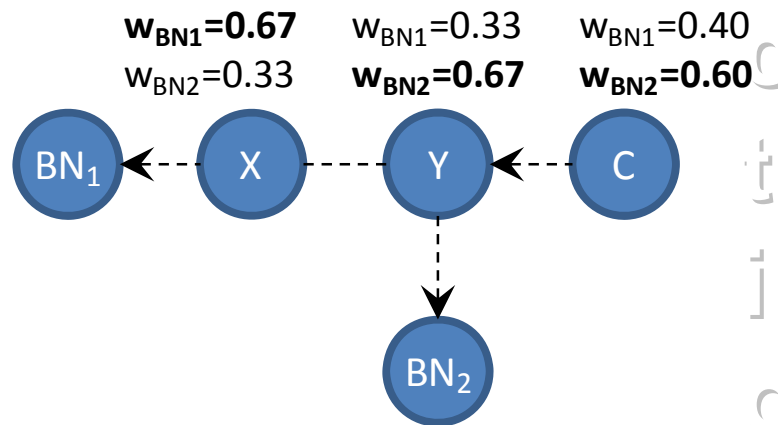
Google maps browsing: HTTP intensive communication

- *very frequent* interactions with *limited payload size*

n Bandwidth limitation towards BNs

- periodic *weights re-evaluation* accordingly to really achieved throughput
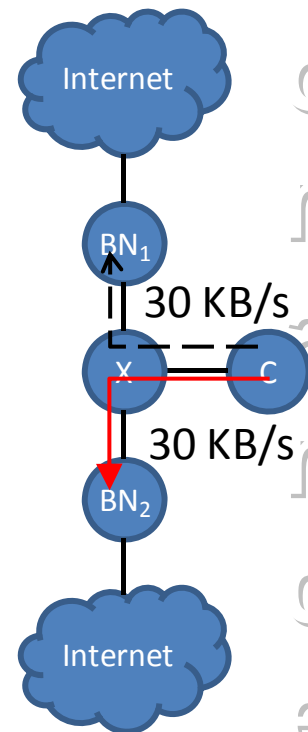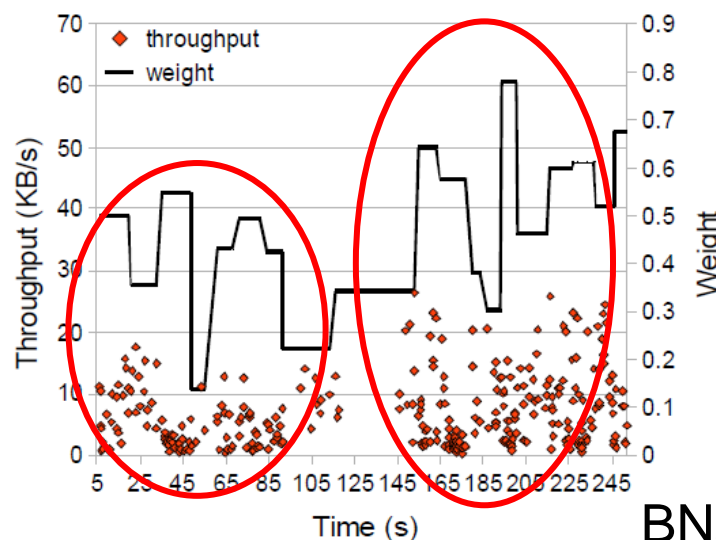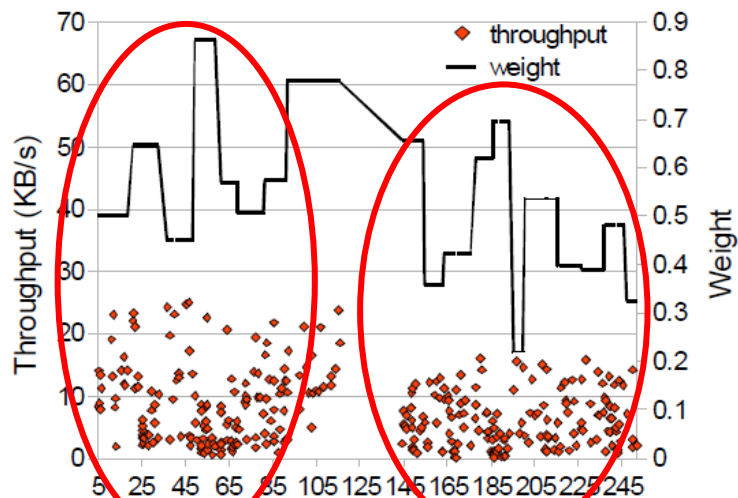- bandwidth allocation swap after 105s

BN_1

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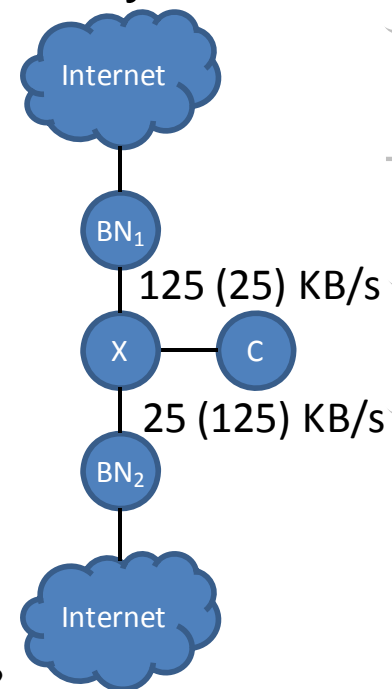
- Same bandwidth allocation, *both L3 and L7 approaches simultaneously*
  - L3 path towards BN_1, L7 path towards BN_2
  - throughputs are similar, *L3 path slightly better*
  - *L7* path weight tend to be *slightly lower*
- Approach swap after 125s
  - weights change accordingly after few iterations

BN_1

BN_2

- n RAMP supports *multi-hop service-oriented* communication in *heterogeneous spontaneous networks*
  - ❑ easy-to-use API for service development by non-expert programmers
- n *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*

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

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/**

n **MANET**

- ❑ **homogeneous** wireless technology
- ❑ usually targeted to a **specific application** with given constrains (e.g., energy, throughput...)
- ❑ **many** nodes with high **mobility** degree

n **Spontaneous networking**

- ❑ very **heterogeneous** node capabilities
- ❑ **general-purpose** environment
- ❑ medium node mobility