Smart Communications via a Tree-based Overlay over Multiple and Heterogeneous (TOMH) Spontaneous Networks

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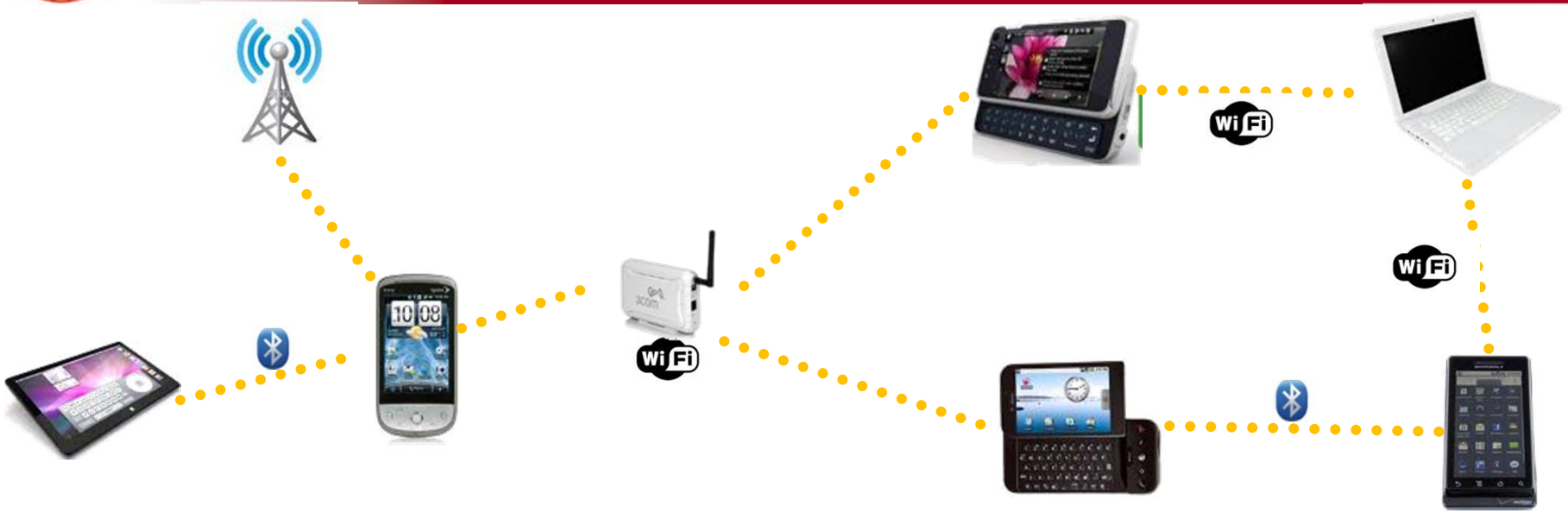
Agenda

- **Scenario**
  - Spontaneous Networking
  - Benefits vs. Issues of Spontaneous Networking
- **TOMH** Design and Philosophy
  - Tier-based Architecture
  - Tree-based Overlay Guidelines
- **TOMH** Overlay Construction
- **TOMH** Overlay Evaluation

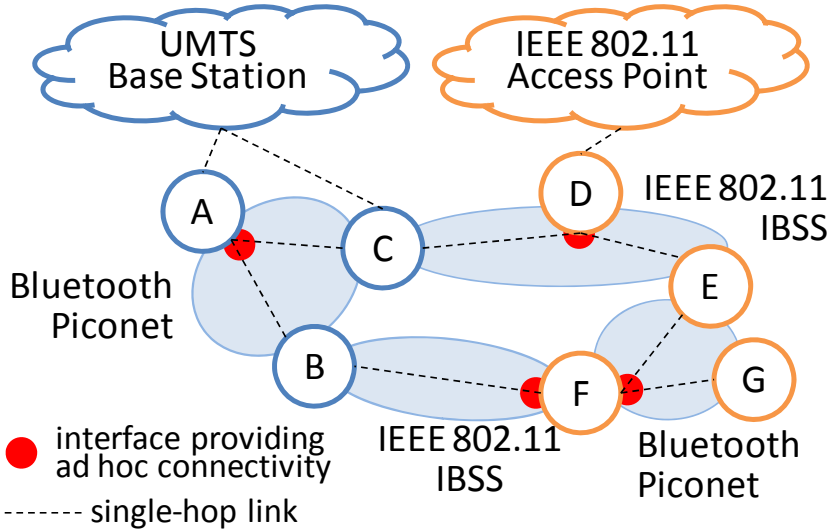
Spontaneous Networking - SN (1)



- **Impromptu** interconnection of mobile and fixed nodes
  - users willing to share content and resources
- **Maximize** interconnected nodes and **available services**
  - **heterogeneous** wireless technologies
  - both infrastructure and **ad-hoc** connectivity
  - **multiple** connectivity opportunities

SN (2)

- Node **cooperation** to
  - provide single-hop connectivity
  - manage multi-hop connectivity
  - support peer-to-peer services



- Peer-to-peer **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 reside in **different layer-3** networks

SN Benefits

- **Network Administrator/Service Provider**
  - impromptu exploitation of any available network
  - satisfy larger number of requests with less equipment deployment
  - requests offloading from infrastructured to non-infrastructured networks
- **End-user**
  - improved quality of experience
  - seamless and reliable access to distributed services
  - performance improvement, e.g. concurrent exploitation of multiple network interfaces

SN Issues

- **Heterogeneous** nodes
  - IEEE 802.11, Bluetooth, Ethernet, Cellular
  - several operating systems and platforms
- **Un-coordinated** network management
  - localized provisioning of layer-2/3 connectivity
  - interconnection of heterogeneous layer-3 networks
- Erratic and **unpredictable behavior**
  - nodes abruptly create and destroy pieces of network (link recovery/failure)
  - nodes dynamically join/move/leave⇨Need to efficiently and promptly **spread state information** among nodes in different networks
- Scenario **complexity** makes hard network management and the development of novel applications

TOMH: Tree-based Overlay over Multiple and Heterogeneous Networks

- **Smart** management of **multiple heterogeneous networks**
  - creation/maintenance tree-based overlay (middleware layer)
  - spreading of network state information
- Collect **global view** of **network conditions**
  - effective network management (local vs. global decisions)
  - awareness of different exploitable paths to destination
- **Lightweight** overlay construction/management
  - overlay initialization
  - mobility awareness ⇨ reconfigure after node join/leave
- **Hierarchical** information architecture based on node available resources/mobility

TOMH Design and Philosophy

- Design based on **Observe-Analyze-Adapt (OAA)** approach
  - observe dynamic network state
  - analyze state information
  - adapt network **utilization** and **configuration** to ensure **reliable** communication

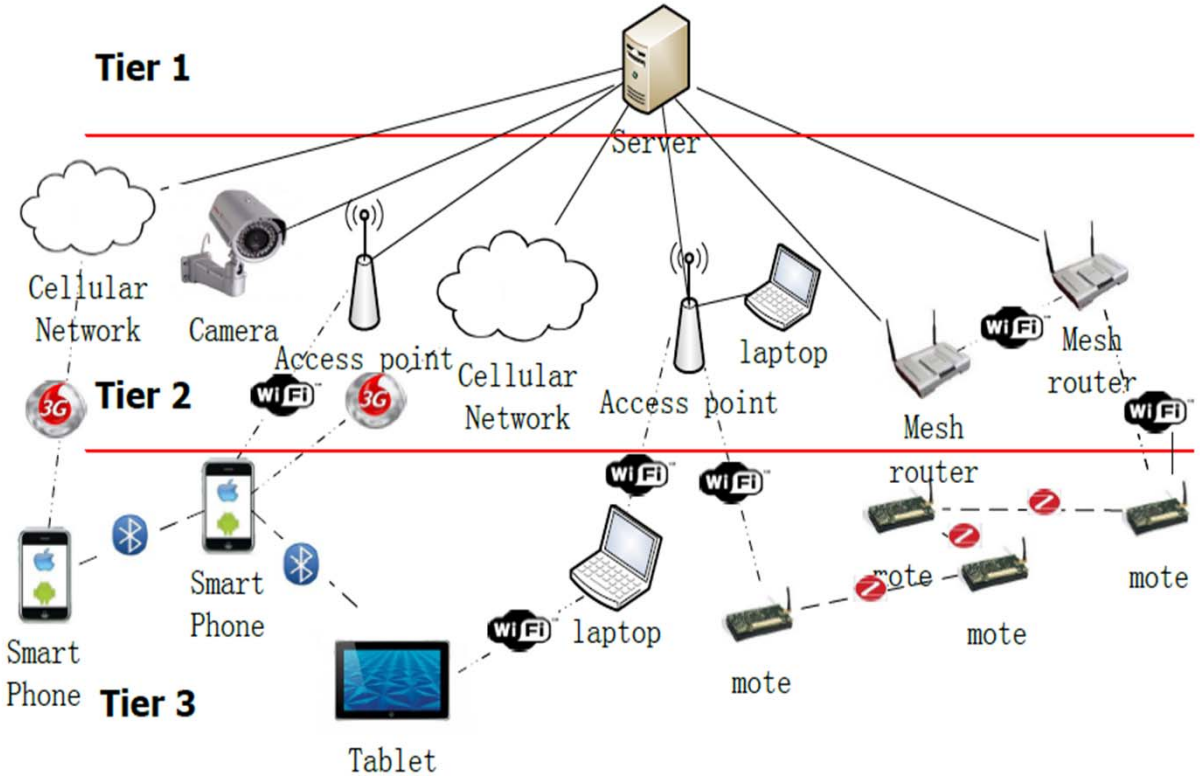
- **Tree-based overlay** organization to address **scalability**
  - tiered and **hierarchical** architecture
  - bottom-up state information aggregation

TOMH Design and Philosophy (2)

- Nodes are **heterogeneous** and links have different **capabilities**
  - **ethernet** devices are **stationary** and **powered**
  - **wireless** devices are **mobile** and **battery** operated

- **Tier-based** architecture
  - logical Tier depending on **hw/sw capabilities** and **connectivity type**
  - **higher tier** ⇨ more **stable** and **resource rich** devices
  - higher tier nodes as aggregation nodes

TOMH: Tier-based Architecture



- **Tier 1**: logically centralized **server** collects network state information
- **Tier 2**: **stationary**, resource capable nodes (e.g., routers, APs, PCs)
- **Tier 3**: **mobile** nodes (e.g., smartphones, laptops, tablets)

- **Multi-tree topology** (not in the scope of this work)
- **Tier 3** nodes are connected to **Tier 2** either **directly** or by intermediary **relay** nodes
- **Tier 3** nodes are more likely to **disrupt** links (un/willingly)

TOMH: Tree-based Overlay Guidelines

- **Communication** over Overlay **enabled** by **RAMP** (Real Ad-hoc Multi-hop Peer-to-peer)

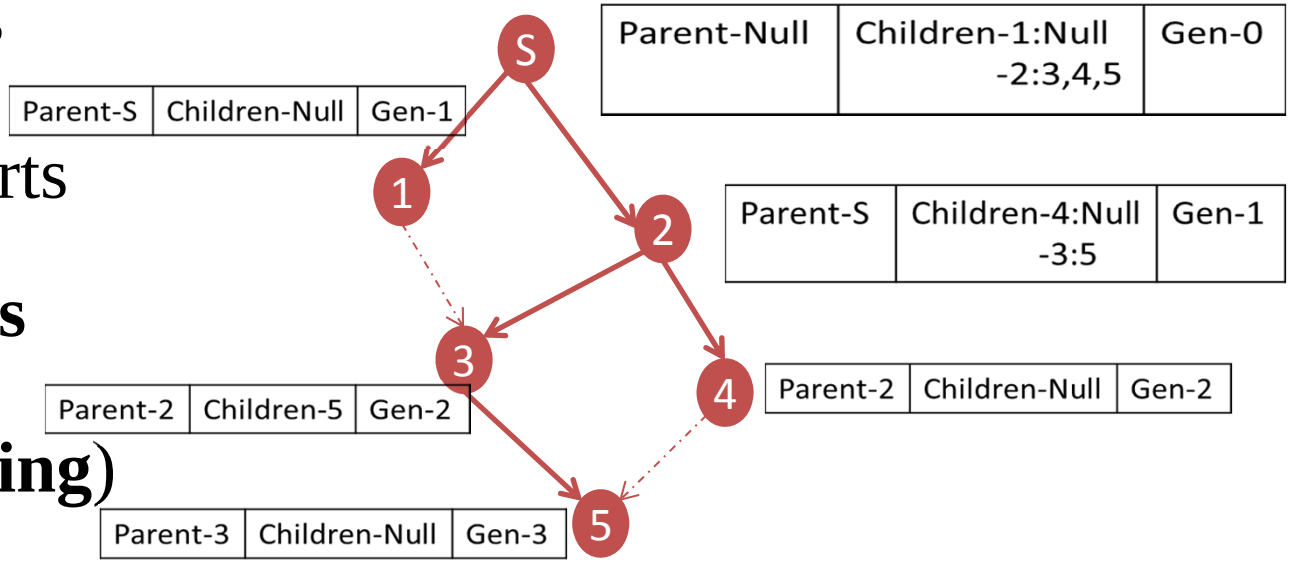
- **Easy-to-use** middleware for **transparent** spontaneous network management in relation to
  - operating system
  - wireless technology
  - layer-3 network configuration
  - node mobility

- Design **criteria**
  - **low overhead**: involve few nodes in overlay changes
  - **promptness**: rapidly react to nodes join/leave (min e2e delay)
  - **mobility** awareness: consider mobility and intermittent connectivity

- Prototype code (Java) and implementation insights
  - `http://lia.deis.unibo.it/research/RAMP/`

TOMH Overlay Construction

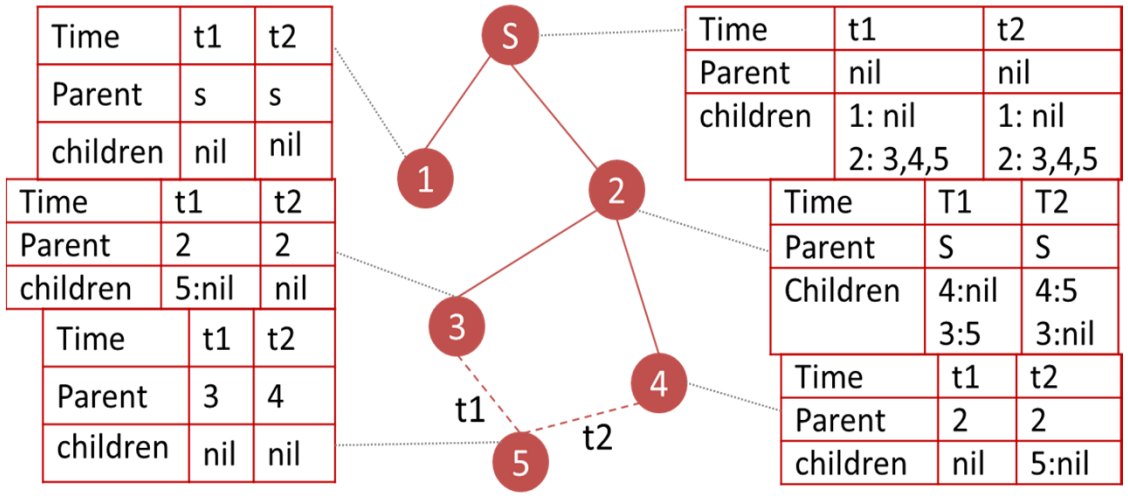
- **Initialization** vs **Maintenance**
- Construction starts from **root** node (server) to **leaves**
- Iterative process (parent **advertising**)



- A node knows its **parent** and every **descendant** (no order)
  - **UID** (Unique Identifier based on MAC address)
  - limit memory/bandwidth utilization
  - enough to know how to **enroute** packets
- **Generation numbers** to avoid loops ($gen_n = gen_p + 1$)
- After construction, network state info **collection starts**

TOMH Overlay Maintenance

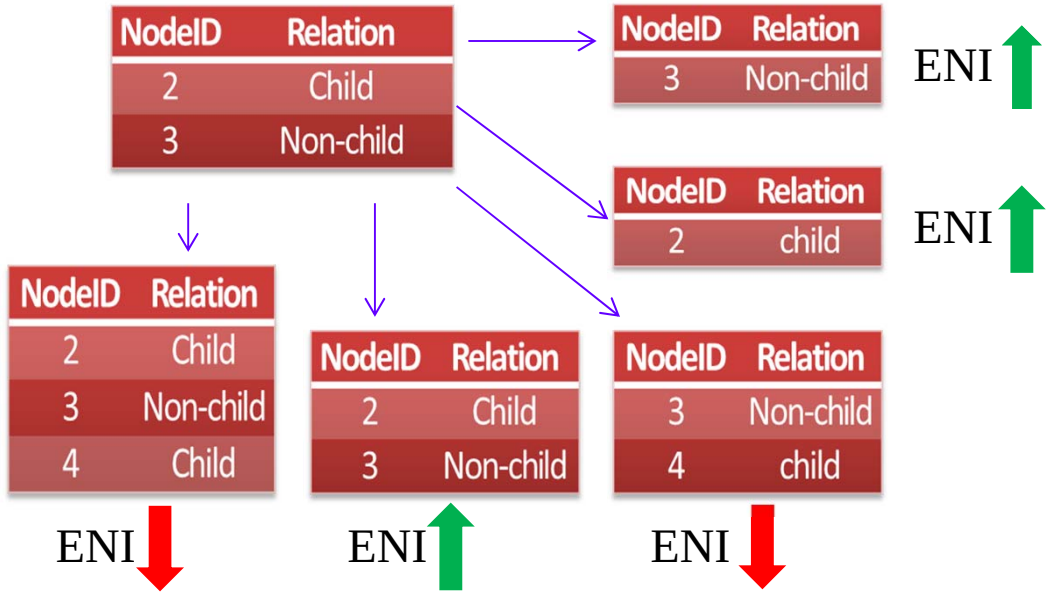
- **Dynamically react** to changes in the **topology**
- **Parent loss** vs. **Children join**
- Parent sends **heartbeat** to its children
- **Timeout** to infer parent loss



- **Parent loss**: new parent selection based on generation number
  - keep children relation only if $gen_{new\_p} <= gen_{old\_p}$ *(avoid loop)*
- **Children join**: propagate update information up to the **most common ancestor** between new and old parent (limit message overhead)

Optimizing Overlay Maintenance: Expected Next Interval (ENI)

- Parents use **heartbeat messages** to keep alive its relationships with children
- Heartbeat responsible for **most** of the **message overhead**
- **Tuning** heartbeat **rate** to achieve **tradeoff** between low overhead and promptness/low e2e delay



- **Dynamic rate adaptation**
  - heartbeat rate adapted depending on overlay actual state
  - *Expected Next Interval* (**ENI**)
  - children know **when** to expect next heartbeat message before considering **parent lost**

Optimizing Overlay Maintenance: Expected Next Interval (ENI) (2)

- ENI used as **timeout** to determine when to **flush** a neighbor relationship

Flush neighbor function is invoked at time 135

NodeID	Lastheardtime	ENI	Action
1	100	10	Delete
2	120	20	Keep
3	130	10	keep

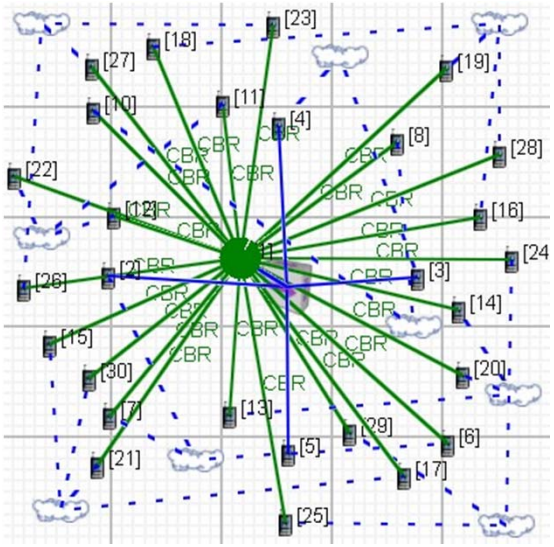
- ENI increased/decreased by the parent depending on **link dynamicity** (slow increase - fast decrease principle)
- **Increase**: $ENI_{current} = ENI_{current} + Delta$
  - *set of children is stable*
- **Decrease**: $ENI_{current} = Max\{ENI_{current}/2 , ENI_{default}\}$
  - *set of children changes*
- **Child joins**: very likely there will be other changes in the near future (decrease ENI to be more reactive)

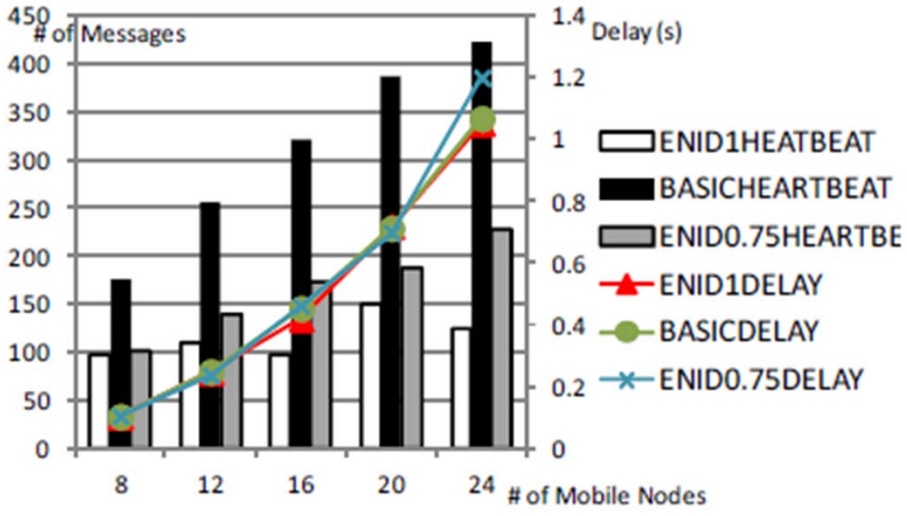
TOMH Overlay Evaluation

- **Simulation** experiments to evaluate our TOMH construction/maintenance protocols
- Comparison with **AODV** and **DYMO** MANET protocols on **CBR** (Constant Bit Rate) application
  - application end-to-end delay
  - message overhead
  - message delivery ratio
- Simulation **scenario**: **1 Tier-1** node as server, **4 fixed Tier-2** nodes, and **[8, 24] Tier-3 mobile** nodes

TOMH Overlay Evaluation (2)

[10m/s, 20m/s] speed range



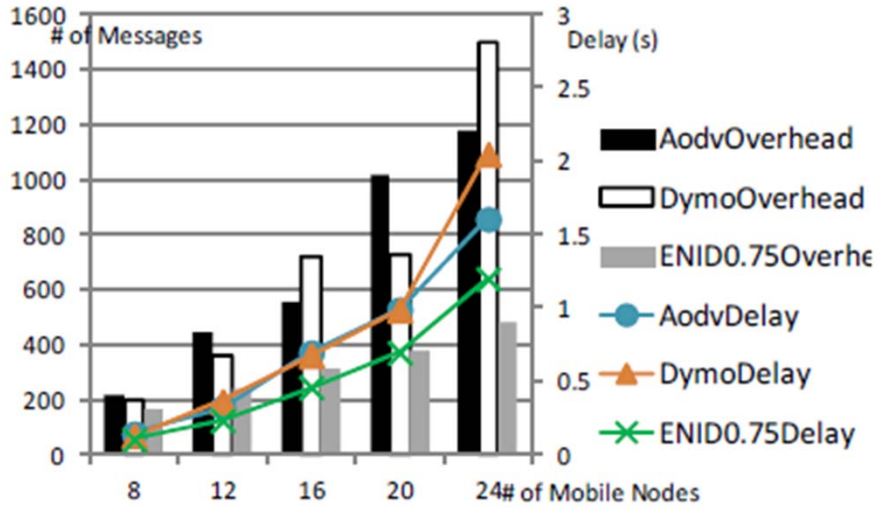


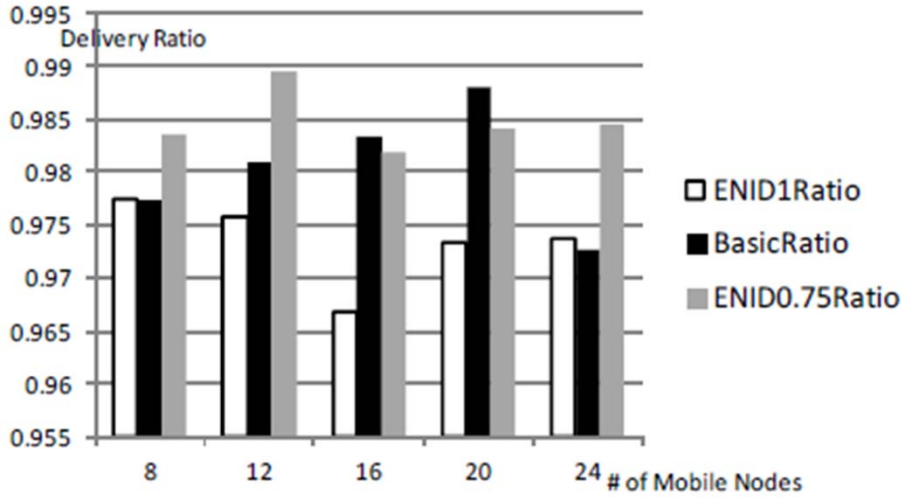
- **QualNET** 5.0.2 simulation environment:
  - **random waypoint mobility** model
  - [1m/s, 2m/s] and [10m/s, 20m/s] **speed** ranges
  - 250s simulation round **duration**
  - $ENI_{default}$ = *7s, Delta = 0,75s/1s*

- **ENI enabled/disabled**
  - heartbeat message **overhead reduced 70% to 42%**
  - **negligible impact** on end-to-end **delay** (avg deviation 1,2%) and **delivery ratio** (max deviation 1,6%)

TOMH Overlay Evaluation (3)

[10m/s, 20m/s] speed range





- **Delta** = 0,75s
  - 60% to 26% less overhead than AODV
  - 68% to 20% less overhead than DYMO
  - 65% less end-to-end delay

Conclusions and Ongoing work

- TOMH achieves delivery ratios of over 96,5% and better performance than MANET protocols
- $ENI_{default}$ and *Delta* determine the overall performance of the protocols
  - they depend on average link duration, which is a function of the nodes number, mobility model, and transmission ranges
  - they can be used to further **tune the overhead/delay tradeoff**
- Ongoing work
  - development of analytical tools based on **formal methods for on-the-fly analysis** of TOMH gathered data
  - improvement of dynamic adaptation technique for **tuning state collection parameters** (better and more self-adapting tradeoff)

Any Question?

Thanks for your attention ☺

Questions time…

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