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Cross Layering in MANETs' Design

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IETF: MANET as Internet evolution

MANET IETF WG proposes a view of mobile ad hoc networks as an evolution of the Internet [1]:

- IP centric view ("solve mobile routing problems at the IP layer"), and
- use of a layered architecture

Advantages:

- ➢ support for heterogeneity and interoperability of lower layer technologies
- ➢ Re-use of most of the work done within IP protocol software stacks

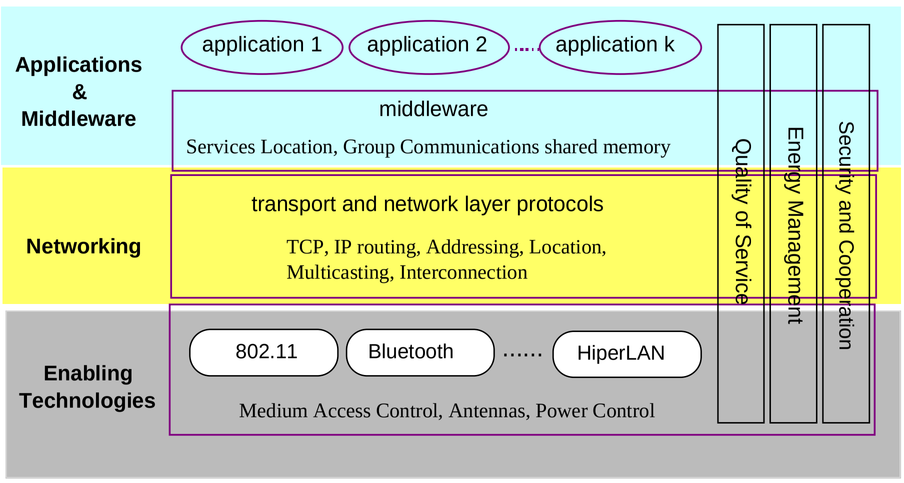
MANET Layered Architecture

- Each layer in the protocol stack is designed and operated independently;
- Static interfaces between layers independent of the individual network constraints, applications, and protocol mechanisms;
- The layered approach leads the research efforts to target mainly isolated components of the overall network design (e.g., routing, MAC, power control).

Advantages: It guarantees that the TCP/IP protocol stack can efficiently operate on a large set of heterogeneous technologies.

Drawbacks: layers independence may produce undesirable effects when applied at ad hoc networks, see for example TCP-MAC interaction problems.

MANET State of the Art



In a MANET some functionalities cannot be assigned to a single layer. Energy management, security and cooperation, quality of service, among the others cannot be completely implemented in a single layer

An efficient implementation of these functionalities can thus be achieved by avoiding a strict layering approach and taking advantage of the interdependencies between them.

Cross layers' Dependencies in MANET Design

Efficient solutions for ad hoc networks require a more strict cooperation among protocols belonging to different layers [2]:

for example, from the energy management standpoint, power control and multiple antennas at the link layer are coupled with scheduling at *MAC* layer, and with energy-constrained and delay-constrained routing at network layer

The question is to what extent the pure layered approach needs to be modified?

- Extension of the layered architecture: layer triggers

  Layer triggers are pre-defined signals to notify some events to the higher layer, *e.g.*, failure in data delivery.

- Violation of the layered architecture: full cross layering design

  Neglecting the layers separation principle by a joint design of the protocols

Cross layers' Dependencies: Layer triggers

Wired Internet: *e.g.*, the Explicit Congestion Notification (ECN) mechanism.

Wireless networks: Corson [3] proposed to add L2 triggers between the link layer and IP to efficiently detec, at the IP layer, changes in link status.

In MANET, the use of layer triggers has been extensively proposed for fixing the problems due to TCP - IP - *MAC* interactions, *e.g.*, Route Failure and Route Re-establishment notifications, to minimize the impact of mobility and link disconnection on TCP performance

Are standardized Layer Triggers an adequate compromise to achieve cross-layer optimization still maintaining a layered architecture?

From Layer triggers to Cross Layering

Recently, for fixing the problems due to TCP - IP - MAC interactions, in addition to the use of layer triggers it has been proposed a "cross-layer" design of protocols mechanisms.

For example in [3] :

Zhenghua Fu, Petros Zerfos, Kaixin Xu, Haiyun Luo, Songwu Lu, Lixia Zhang, Mario Gerla, "The Impact of Multihop Wireless Channel on TCP Throughput and Loss", Proc. Infocom 2003, San Francisco, April 2003.

two link level mechanisms, Link RED, and adaptive spacing, are introduced to improve TCP efficiency in ad hoc network

- The Link RED provides TCP with an early sign of overload at link level;
- Adaptive spacing is introduced to improve spatial channel reuse, thus reducing the risk of stations starvation.

Cross Layering Examples (I)

Physical-MAC-Network cross-layer design

In [4] the authors propose to use the channel reservation control packets employed at the MAC layer (i.e., RTS/CTS packets in 802.11)

- to make real-time estimations of the channel status (i.e., SNR). These estimates are then provided at the physical layer for an adaptive selection of a spectrally efficient transmission rate.
- the information gathered at the MAC layer are exploited at the routing layer (for example) to select routes the minimize interference at the link layer.

Cross Layering Examples (II)

Routing and the middleware layer cross-layer design

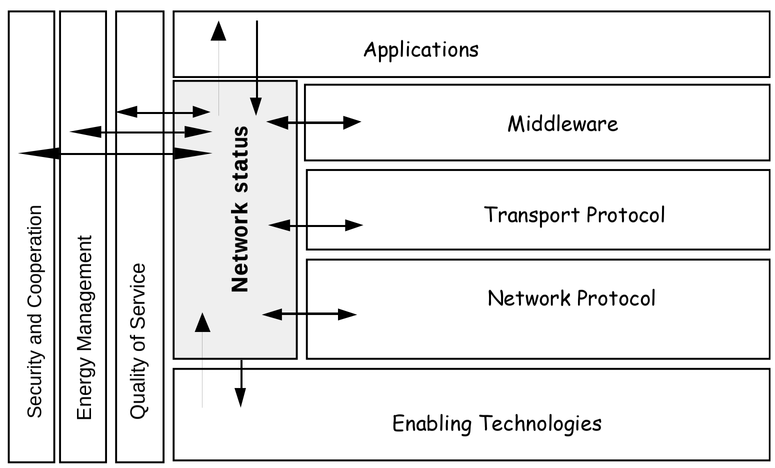
In [5] the authors apply the cross-layer design principle to the routing layer and the middleware layer to facilitate multimedia data accessibility for various applications at the end-systems.

- The middleware layer utilizes the nodes' location and movement pattern to predict future connectivity of a group, and to decide when and where data needs to be replicated.
- The routing layer utilizes the data priority information to differentiate and prioritize network level packets for scheduling purpose.

Moreover, the routing and the middleware layers actively communicate with each other via signaling to jointly adapt the service provided to the applications to current network conditions.

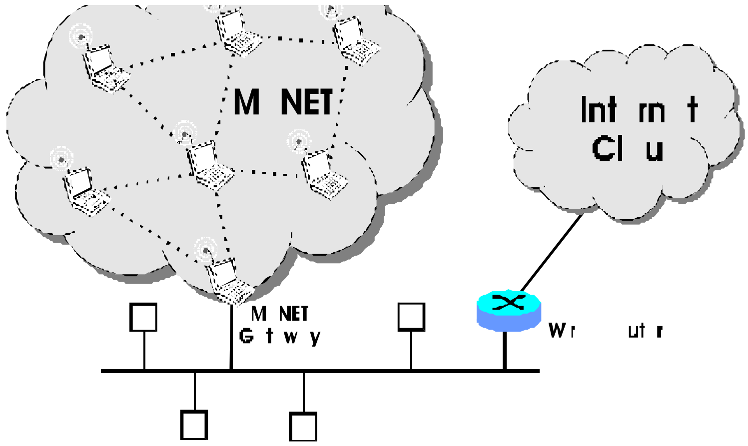
A Full Cross Layering Architecture

Hereafter, I will present and discuss some ideas about MANET cross-layering design that are emerging in the framework of the MobileMAN project [6]



the kernel of the architecture is a shared memory ("Network Status" in the figure) that is a repository of all the network status information collected by the network protocols. All protocols can access this memory to write the collected information, and to read information produced/collected from the other protocols.

Ad Hoc network realistic view



MANET scales:

small-scale (i.e., 2-20 nodes)
moderate-scale (i.e., 20-100 nodes)
large-scale (i.e., 100+ nodes)
very large-scale (i.e., 1000+ nodes

- Small-medium scale ad hoc islands
- Ad hoc islands interconnected to the Internet

Ad Hoc network realistic view

The Ad Hoc network is a subnet based on "ad hoc" protocols

Ad Hoc Node
Applications and Middleware
Socket API
Simplified Transport Protocol
Subnetwork Forwarding and Routing
Wi-Fi or Enhanced Wi-Fi cards

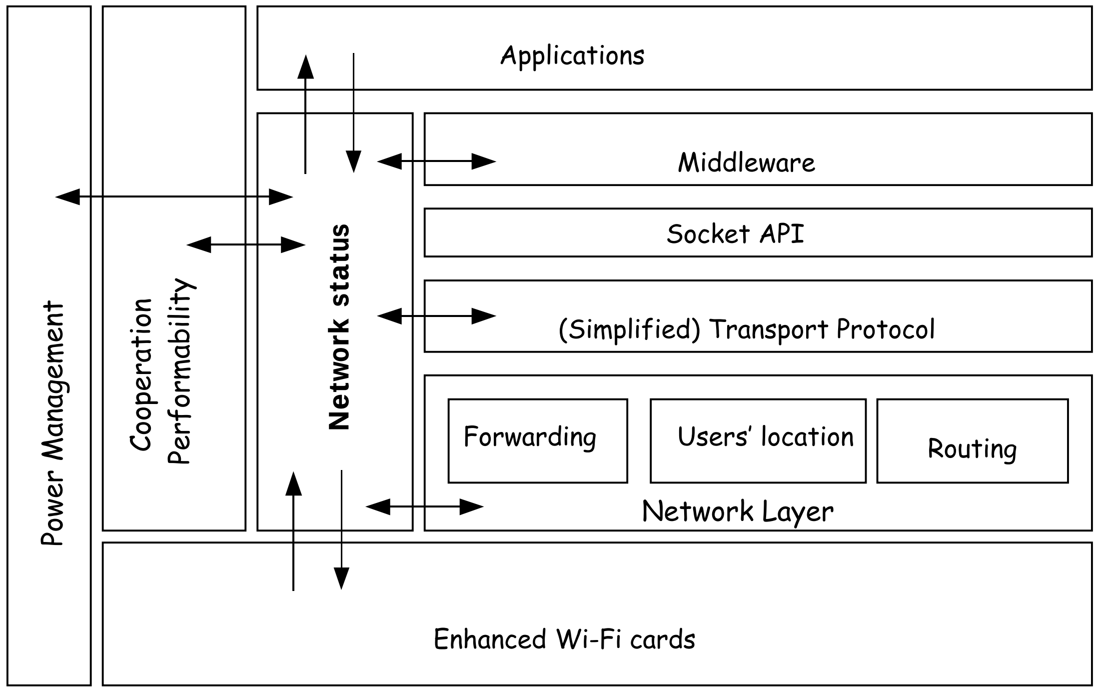
Ad Hoc Node

Proxy-based architecture for the connection to the Internet

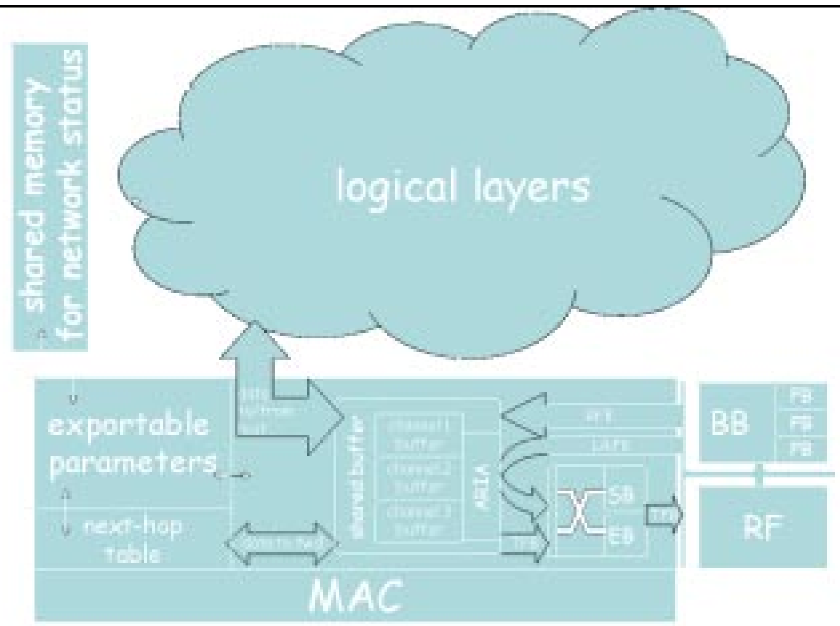
Proxy daemon	
Socket API	Socket API
Simplified Transport Protocol	TCP
Subnetwork Forwarding and Routing	IP
Wi-Fi or Enhanced Wi-Fi	Subnetwork

Proxy

MobileMAN Cross Layer Architecture



Cross Layering at MAC layer



Cross layering: A key component of the proposed architecture is the access to MAC parameters and variables from the higher layers, and the possibility to utilize at the MAC level the information collected by higher layers and available in the shared memory.

This let open the doors to a more performing global architecture with layers interaction.

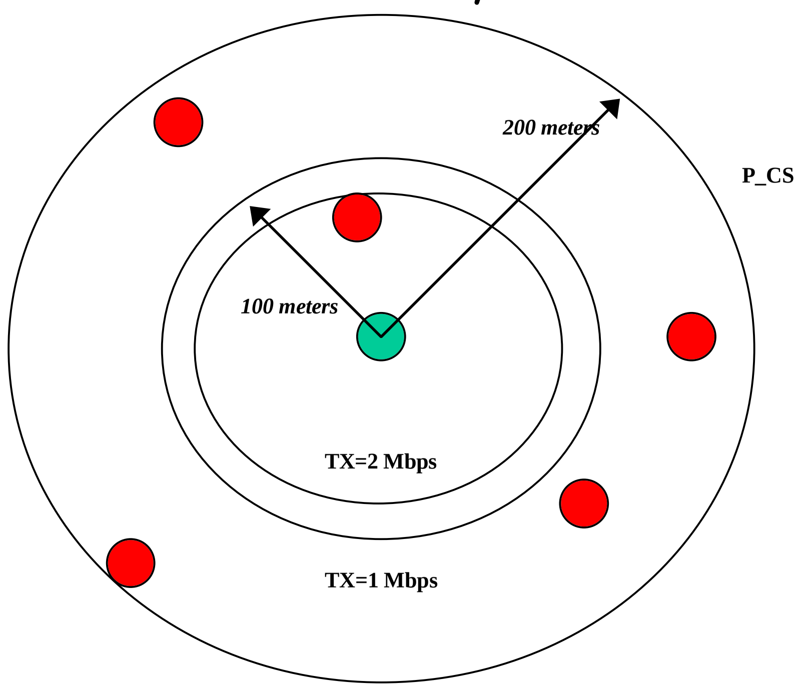
Cross Layering Potentialities at MAC level (I)

Exploiting Topology/Routing information at MAC Layer

Two-Three hops neighbors are typically "conflicting"

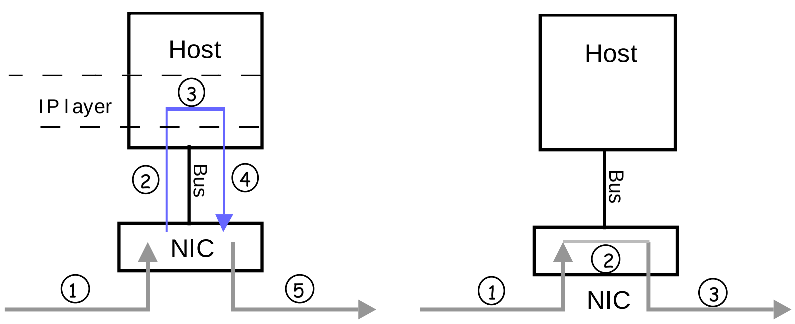
RTS/CTS mechanism is not useful

The MAC layer could exploit the routing/topology information to reduce the impact of phenomena such as: exposed nodes, capture phenomena etc.



Cross Layering Potentialities at MAC level (II)

Forwarding performed at MAC layer: Exploiting at the MAC layer the routing information collected by higher layer, and following the approach proposed in [7], it is possible to implement at the MAC level an efficient packet forwarding scheme.



Cross Layering Potentialities at MAC level (III)

By exploiting a cross-layering design both local and global adaptation to network conditions can be performed. For example,

- MAC locally reacts to congestion by exponential back off
- When congestion is high a global compensation may be performed:
  - the forwarding mechanism may re-route the traffic to avoid the bottleneck;
  - if an alternative routes do not exist, the transport protocol mechanisms can be used to freeze the traffic sending

Cooperation /Forwarding/Routing/Transport Cross Layering

Let us assume that the network layer through the routing mechanism has a (partial) knowledge of the network topology. This may include

- Alternative routes for a given destination
- Other info on these routes (e.g., number of hops)

The Cooperation function by using these info can try to classify the reliability/performance/cooperation along these routes, and to compute a "performability" metric for each route

The Forwarding function can exploit the metric

- to select among alternative paths
- to perform a load balancing among the routes

Cooperation /Forwarding/Routing/Transport Cross Layering (cont.)

Transport ACKs can be used by the Cooperation function to measure the *performability* of the selected routes, and hence to redefine the related metric.

Finally, a new *performability* measure is provided to the Forwarding function that will use it for selecting the future paths for packets forwarding.

Cross Layering impact on Middleware and Applications

In a layered architecture, a localization service is designed independently by the information already available at lower layers. In a full cross-layer architecture the topology and routing information can be used at the middleware layer to implement a location service avoiding overheads for nodes' location.

At the application layer, cross layering makes possible a full context awareness of the underlying network context, and hence to achieve better performance, see e.g., the design of a peer-to-peer system on top of ad hoc networks [8].

Cross Layering Pros

Cross Layer optimization for all network functions. Cross layering is a must for functions such as energy management, but provides benefits for all network functions.

Both *local and global adaptation* can be performed to adapt the system to highly variable ad hoc network conditions, and to better control the system performance

Full Context Awareness at all layers. At each layer, protocols can be designed to be aware of the network status, energy level, etc. Cross layering makes easy to achieve context awareness at the application layer.

Reduced overhead for collecting the network status information avoiding data duplication at different layers.

Cross Layering Cons

- Protocols re-design
- No independence from the underlying technologies
- Interconnection to the Internet is not straightforward

Cross Layering Open Issues

- How should the network status information managed?
- How protocols belonging to different layer access to the common information?
- How should global system constraints and characteristics be factored into the protocol designs at each layer?
- We need to re-design all the protocol stack, or we can adapt existing protocols?
- Protocols overheads cannot be evaluated in isolation but new cross-layer metrics need to be defined.

References

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