Distributed Computing in Mobile Ad Hoc Networks

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Outline

(1) Motivations – Invisible Global Infrastructure

Internet Vision (Kleinrock, 2004)

New vision for the Internet can be broken down into five *elements*:

- the Internet technology will be everywhere,
- it will be always accessible,
- it will be always on,
- anyone will be able to plug in from any location with any device at any time,
- it will be invisible.

Three *dimensions* form a new “space” of Internet:

- nomadicity,
- embeddedness and
- ubiquity.

(1) Motivations – Invisible Global Infrastructure

Nomadicity – the system support needed to provide a rich set of computing and communication capabilities and services to nomads as they move from place to place in a way that is transparent, integrated, convenient and adaptive.

Embeddedness – small intelligent devices embedded in the physical world and connected to the Internet.

Ubiquity – Internet service availability wherever the nomad travels on a global basis.

Nomadic computing – the mobile or nomadic user seeks to be provided with trouble-free Internet access and service from any device, any place, at any time.

(1) Motivations – Invisible Global Infrastructure

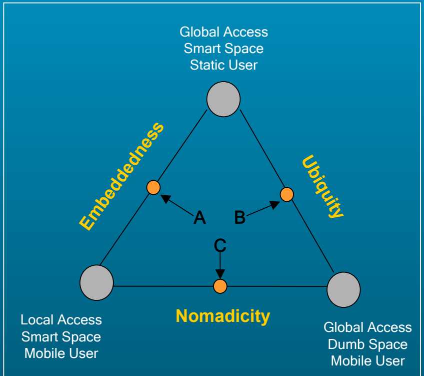


Fig. 1-1. The triangle of nomadicity, embeddedness and ubiquity.

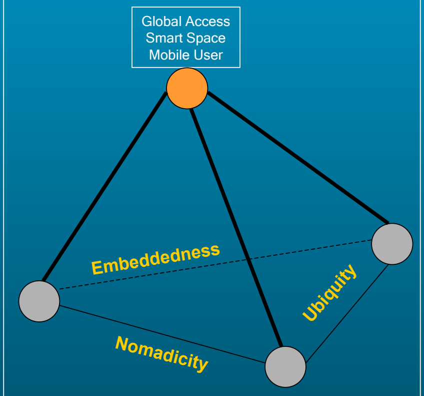


Fig. 1-2. The invisible global infrastructure (IGI).

(2) Introduction to Mobile Ad Hoc Networks

Mobile ad hoc networks (MANETs) are composed of autonomous mobile stations (*hosts*) communicating through wireless links, without any fixed backbone support – in a decentralized manner.

Mobile hosts can thus exchange information in areas that do not have a pre-existing infrastructure.

A message sent by host may be received by all the nodes (that is hosts) in its vicinity, i.e., by all of its *neighbors*.

Hosts can come and go or appear in new places; so with an ad hoc network, the topology may be changing all the time (without warnings) – such networks can get partitioned and reconnected.

Each node in MANETs functions as both a computing host and a router; the control of the network is distributes among the nodes.

(2) Introduction to Mobile Ad Hoc Networks

Among the possibilities of use mobile ad hoc networks i.e. are (Tanenbaum, 2003):

- military vehicles on battlefield,
- a fleet of ships at sea,
- emergency workers at an earthquake that destroyed the infrastructure,
- a gathering of people with notebook computers in a area lacking 802.11:

(i) non-802.11 mode (Lucent),

(ii) independent BSS[1] mode.

[1] *Basic Service Set*

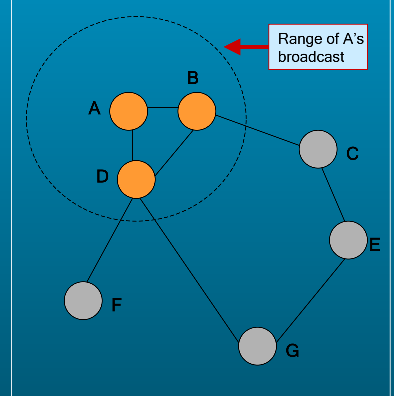


Fig. 2-1. Example of MANET.

(2) Introduction to Mobile Ad Hoc Networks

IEEE Wireless 802.11 Standards

WLANs can operate in one of two configurations: with a *access point* (AP) and without access point – ad hoc network.

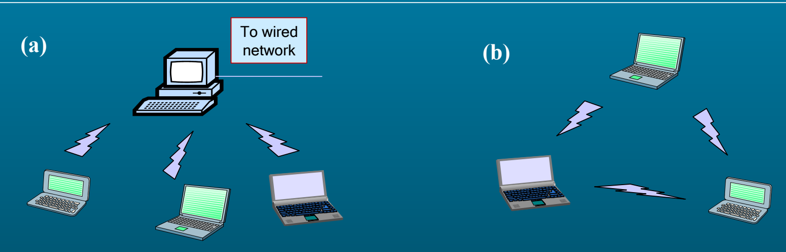


Fig. 2-2. (a) Wireless network with access point; (b) ad hoc network.

(2) Introduction to Mobile Ad Hoc Networks

IEEE Wireless 802.11 Standards

802.11 standard specifies five transmission techniques allowed in physical layer:

- infrared method – 1997,
- Frequency Hopping Spread[2] Spectrum (FHSS) – 1997,
- Direct Sequence Spread Spectrum (DSSS) – 1997,
- Orthogonal Frequency Division Multiplexing (OFDM) – 1999,
- High Rate Direct Sequence Spread Spectrum (HR-DSSS) – 1999.

In MAC sublayer (IEEE data link layer is subdivided into MAC and LLC sublayers) 802.11 support two modes of operation: *Distributed Coordination Function* (DCF) and *Point Coordination Function* (PCF).

[2] The amount of information that electromagnetic wave can carry is related to its bandwidth:

$$\Delta f = \frac{c\Delta\lambda}{\lambda^2}$$

(2) Introduction to Mobile Ad Hoc Networks

IEEE Wireless 802.11 Standards

When DCF is employed, 802.11 uses a protocol called *Carrier Sense Multiple Access / Collision Avoidance* (CSMA/CA).

Two methods of operation are supported by CSMA/CA: collision detection (with Ethernet backoff algorithm) and collision avoidance.

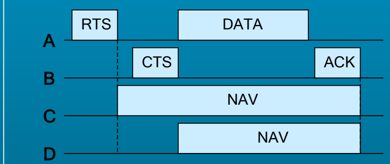
CSMA/CA – with collision avoidance – is based on Multiple Access with Collision Avoidance for Wireless (MACAW) protocol (**Fig. 2-3**).

In PCF the access point polls the other stations, asking them if they have any frames to send.

The basic mechanism is for the access point to broadcast a *beacon frame* periodically; it contains system parameters and it also invites new stations to sign up for polling service.

PCF and DCF can coexist within one network-cell (**Fig. 2-4**).

(2) Introduction to Mobile Ad Hoc Networks



RTS - Request To Send
CTS - Clear To Send
NAV - Network Allocation Vector

Fig. 2-3. CSMA/CA: *A* wants to send to *B*, *C* is a station within range of *A*, *D* is a station within range of *B* but not within range of *A*.

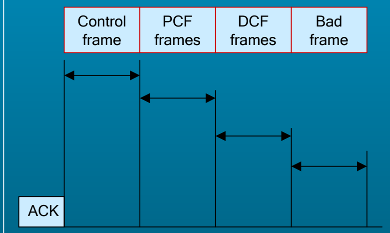


Fig. 2-4. Interframe spacing in 802.11

(2) Introduction to Mobile Ad Hoc Networks

Standard	Frequency [GHz]	Spread	Data rate [Mbit/s]
IEEE 802.11-DS	2,4	DSSS	1 / 2
IEEE 802.11-FH	2,4	FHSS	1 / 2
IEEE 802.11b	2,4	DSSS	1 / 2 / 5,5 / 11
IEEE 802.11g	2,4	OFDM	6 / 9 / 12 / 18 / 24 / 36 / 48 / 54
IEEE 802.11a	5	OFDM	6 / 9 / 12 / 18 / 24 / 36 / 48 / 54

Tab. 2-1. IEEE 802.11 wireless standards.

Other IEEE wireless standards:

- 802.16 – “Air Interface for Fixed Broadband Wireless Access Systems”, wireless MAN;
- 802.15 – Bluetooth.

(3) Mobile Ad Hoc Network Model

The topology of the ad hoc network is modeled by a undirected graph $G = (V,E)$, where V is the set of nodes (hosts-routers) and E is the set of links between neighboring nodes (that is between nodes that can communicate directly).

Since the nodes are mobile, the E set changes with time.

We assume that links between two adjacent nodes are always bidirectional and every node $v \in V$ has a unique physical address or id.

G_C : the V set can change with time.

G_{NC} : the V set does not change with time.

G_P : graph G can get partitioned[3] and reconnected.

G_{NP} : graph G does not get disconnected (partitioned).

} $G_{C|P}$, $G_{C|NP}$, $G_{NC|P}$, $G_{NC|NP}$

[3)] Partitioning fragments the graph into isolated subgraphs called partitions (there is a path in E for any two nodes in the same partition but there is not a path in E for any two nodes in different partitions).

"Ad hoc routing is a red-hot research area", (Tanenbaum, 2003).

Frequent topology changes caused by node mobility in MANETs make routing in ad hoc networks a challenging problem.

Routing protocols can be classified into three different groups (Abolhasan, Dutkiewicz and Wysocki, 2003):

• global/proactive – the routes to all the destinations are determined at the start up and maintained by using periodic route update process;

• on-demand/reactive – the routes are determined when they are required by the source using a route discovery process;

• hybrid – combine the basic properties of the first two classes of protocols into one.

Ad Hoc On-Demand Distance Vector (AODV) (Perkins and Royer, 1999)

AODV is a reactive routing protocol, that is it determines a route to some destination only when some host wants to send a packet to that destination.

The Algorithm.

```
struct ROUTE_REQUEST {
        src_addr;    //typically IP address
        request_id; //incremented whenever a ROUTE_REQUEST is broadcast
        dest_addr;
        dest_seq;    //the most recent value of Pj's sequence value that Pi has seen
        hop_count  //keep truck of how many hops the packet has made
} ■
struct ROUTE_REPLY {
        src_addr;   dest_addr; // copied from incoming ROUTE_REQUEST
        dest_seq;  //taken from local counter in memory
        hop_count;
        lifetime    //controls how long the route is valid
} ■
```


Ad Hoc On-Demand Distance Vector Protocol

• If P_i does not have entry in *routing table* for P_j, it has to discover a route to P_j (this property makes this algorithm "on-demand") by construct and broadcast ROUTE_REQUEST packet. ■

• When a ROUTE_REQUEST packet arrives at a node P_k ($k \neq j$), it is processed in the following steps:

(1) <*src_addr*, *request_id*> is looked up in a local *history table*: (i) if this request has already been processed, it is discarded and processing stops; (ii) if it is not a duplicate, the pair is entered into the *history table*.

(2) P_k looks up the destination in its *route table*: if $dest\_seq_{rt} \geq dest\_seq$ a ROUTE_REPLY packet is sent back to the source ($dest\_seq_{rt}$ – sequence number stored in the local *routing table*); else step (3) is executed.

Ad Hoc On-Demand Distance Vector Protocol

(3) P_k increments the *hop_count* field and rebroadcasts the packet; data from packet are stored as a new entry in local *reverse route table* (a timer is also started for newly-made reverse route entry). ■

• In response to the incoming request, Pj builds a ROUTE_REPLY packet and unicast it to the node that the ROUTE_REQUEST packet came from. ■

• At each node on the way back (ROUTE_REQUEST) *reverse route table* is used to unicasts the packet to the source; local host also updates[4)] its *routing table* if one (or more) of the following three conditions are met: (i) no route to P_j is know, (ii) the sequence number for P_j in the ROUTE_REPLY packet is greater than the value in the *routing table*, (iii) the sequence numbers are equal but the new route is shorter. ■

• Periodically, each node broadcast a *Hello* message for route maintenance. ■

[4)] In this way, all the nodes on the reverse route learn the route to P_j as a byproduct of P_i discovery.

(4) Routing in Mobile Ad Hoc Networks

Ad Hoc On-Demand Distance Vector Protocol

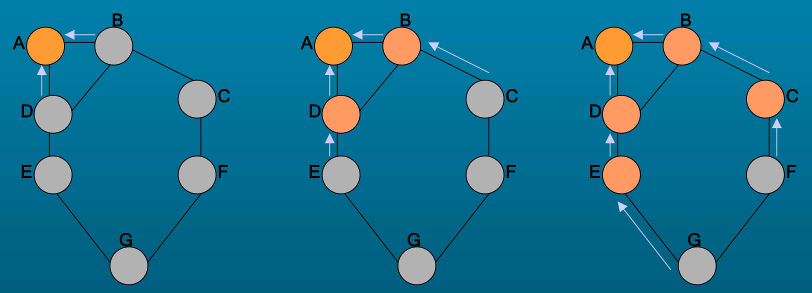


Fig. 4-1. Route discovery from ***A*** to ***G*** (arrows indicate reverse routes).

(4) Routing in Mobile Ad Hoc Networks

Other routing protocols for ad hoc networks (Abolhasan, Dutkiewicz and Wysocki, 2003):

- **proactive** – Destination-sequenced distance vector (DSDV), Wireless routing protocol (WRP), Global state routing (GSR), Fisheye state routing (FSR), Source-tree adaptive routing (STAR), Distance routing algorithm for mobility (DREAM), Cluster-head gateway switch routing (CGSR);
- **reactive** – AODV, Dynamic source routing (DSR), Routing on-demand acyclic multi-path (ROAM), Light-weight mobile routing (LMR), Temporally ordered routing algorithm (TORA), Associativity-base routing (ABR), Signal stability adaptive (SSA), Cluster-based routing protocol (CBRP);
- **hybrid** – Zone routing protocol (ZRP), Zone-based hierarchical link state (ZHLS), Distributed spanning trees based routing protocol (DST), Distributed dynamic routing (DDR), Scalable location update routing protocol (SLURP).

(5) Replication and Consistency

In ad hoc networks, since mobile hosts move freely, disconnections occur frequently and this causes frequent network division. Consequently, data accessibility in MANETs is lower than in fixed networks.

One possible approach for this problem is to **replicate** information at multiple nodes; but the problem that comes with replication is the danger of inconsistency.

(5) Replication and Consistency

In order to determine the optimal allocation of replicas, we must find a which gives the highest data accessibility considering the following parameters:

(i) the access frequency from each mobile host to each data item;

(ii) the probability that each node will participate in the network and will disappear from the network;

(iii) the probability that each two nodes connected by a link (neighbors) will be disconnected and

(iv) the probability that each two disconnected nodes will be connected.

{Other methods of replica distribution assume that location of the node defines the access probability for each piece of data item (Ishihara, Mizuno, Tamori, Watanabe, 2002).}

(5) Replication and Consistency

Replica Allocation Methods (Hara, 2001)

• Static Access Frequency (SAF): each node allocates replicas of *C* data items in descending order of the access frequencies;

• Dynamic Access Frequency and Neighborhood (DAFN): the access frequency and to each data item and the neighborhood among nodes are taken into account;

• Dynamic Connectivity based Grouping (DCG): shares replicas in larger groups of nodes than the DAFN method; in order to share replicas effectively, each group should be stable, so the DCG creates groups that are *biconnected components*[5)].

[5)] Biconnected component denotes a maximum partial graph *G* which is connected (not divided) if an arbitrary node in the graph *G* is deleted.

(5) Replication and Consistency

Consistency in Partitioned Networks (Davidson, Garcia-Molina, 1985)

When designing a system that will operate when it is partitioned, the competing goals of *availability* and *correctness* must somehow be met.

Correctness can be archived simply by suspending operation in all but one of the partition groups and forwarding updates at recovery (data must be correct when recovery is complete); but this severely compromises availability.

Availability – the system's normal function should be disrupted as little as possible.

(5) Replication and Consistency

Consistency in Partitioned Networks

Classification of strategies:

• *pessimistic strategies* prevent inconsistencies by limiting availability; *optimistic strategies* do not limit availability;

• *syntactic approaches* use on-copy serializability[6)] as their sole correctness criterion; *semantic approaches* use the semantic of the transactions or the semantics of data in defining correctness.

[6)] On-copy serializability – the concurrent execution of operations on a replicated data is equivalent to a serial execution on non-replicated data.

(5) Replication and Consistency

Consistency in Partitioned Networks

	Syntactic Approaches	Semantic Approaches
Optimistic Strategies	Version Vectors The Optimistic Protocol	Log Transformations Data-Patch
Pessimistic Strategies	Primary Site Copy Tokens Voting Missing Writes Accessible Copies Algorithm Class Conflict Analysis	General Quorum Consensus

Tab. 5-1. Survey of solutions for consistency in partitioned networks.

(5) Replication and Consistency

Consistent Update Diffusion in MANETs (Becker, Hähner, Rothermel, 2002)

Earlier solutions that do consider network partitioning approach the problem from the direction of replica consistency in distributed systems and databases; while the problems are similar, several instances of information dissemination in ad hoc networks are different.

Strong consistency may result in MANETs in poor availability if the presence of frequent network partitioning; therefore, weaker consistency levels have been proposed to increase the availability.

In most replica consistency solutions, on merger of partitions the replicas in the merging partitions are synchronized so that they have the same values. This incurs very high communication overheads which are not acceptable in wireless ad hoc networks.

(5) Replication and Consistency

Consistent Update Diffusion in MANETs

Local observation consistent (LOC)

$$\forall_{x} \forall_{x_n \in Copies(x)} :$$

(C1) x_n will eventually converge to the most recently propagated state of x;

(C2) once x_n has reached state x_j^k, it will no longer accept state x_j^l with $l < k$.

{≈ pipelined RAM consistency}

(5) Replication and Consistency

Consistent Update Diffusion in MANETs

Global observation consistent (GOC)

Copies(x) is local observation consistent (C1)(C2) and

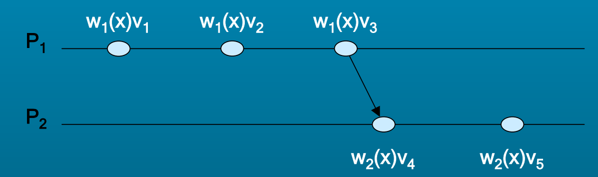
$$\forall_{x} \forall_{x_n \in Copies(x)} :$$

(C3) once x_n has reached state x_i^k, it will no longer accept state x_j^l with $x_j^l \to x_i^k$.

{≈ casual consistency}

(5) Replication and Consistency

Consistent Update Diffusion in MANETs



P_2 **LOC** serialization: $w_1(x)v_1 \mapsto_2 w_2(x)v_4 \mapsto_2 w_1(x)v_3 \mapsto_2 w_2(x)v_5$

P_2 **GOC** serialization: $w_1(x)v_1 \mapsto_2 w_1(x)v_3 \mapsto_2 w_2(x)v_4 \mapsto_2 w_2(x)v_5$

~~$w_1(x)v_2$~~

Fig. 5-1. Local and global observation consistency example.

(5) Replication and Consistency

Consistent Update Diffusion in MANETs

Original LOC and GOC algorithms are based on flooding[7)].

Consistent update diffusion with LOC or GOC allows also for variety monitoring, tracking and navigation using global information.

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7) Flooding – a source *s* sends the message to all its neighbors; when a node other than destination *d* receives the message the first time it re-sends it to all its neighbors.

(6) Self-stabilization Systems

*"We call the system '**self-stabilizing**' if and only if, regardless of the privilege selected each time for the the next move, at least one privilege will always be present and the system is guaranteed to find itself in a legitimate state after a finite number of moves",* (Dijkstra, 1974).

Self-stabilization is amenable to the layered approach, (Schneider, 1993).

We could denote that if *S* is self-stabilizing with respect to *P* then *TRUE* ⮈ *P* in *S*.

The relation ⮈ is transitive, if *Q* ⮈ *P* and *P* ⮈ *R*, then *Q* ⮈ *R*.

Informally we can see how transitivity corresponds to the technique of layering:

given S_1 satisfying *Q* ⮈ *P* and S_2 satisfying *P* ⮈ *R*, we combine S_1 and S_2 such that S_2 reads from the variables of S_1 to produce a new program satisfying *Q* ⮈ *R*.

Most interesting self-stabilizing algorithms for MANETs: mutual exclusion, spanning tree construction and other graph theory problems.

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