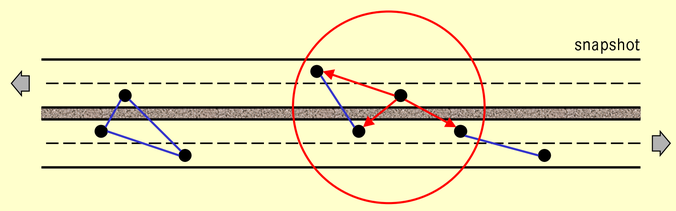
DAIMLERCHRYSLER

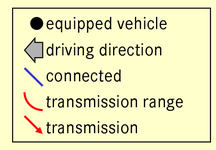
Technische Universität Berlin
Fachbereich Informatik

Localized Group Membership in Highly Mobile Ad Hoc Networks

Inter-vehicle Communication

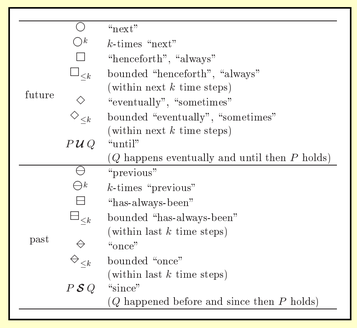
- Use radio communication devices with range ~½ mile
- Employ positioning systems (GPS) and vehicular sensors
- Exchange information on speed and location to identify traffic jams





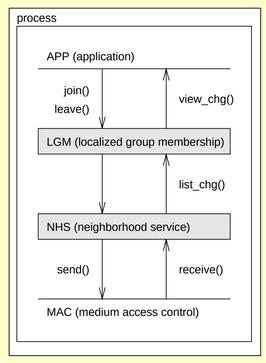
Mobile Ad Hoc Networks

- (Highly) mobile hosts
- Absence of infrastructure
  → decentrally organized
- Limited communication range
  → transiently connected and partitionable
- Broadcast within range
  → point-to-multipoint communication
- Large-scale and potentially unbounded
  → only aware of own ID; no fixed number of hosts



future	$\bigcirc$	"next"
	$\bigcirc^k$	k-times "next"
	$\Box$	"henceforth", "always"
	$\Box_{\leq k}$	bounded "henceforth", "always" (within next k time steps)
	$\Diamond$	"eventually", "sometimes"
	$\Diamond_{\leq k}$	bounded "eventually", "sometimes" (within next k time steps)
	$P \,\mathcal{U}\, Q$	"until" (Q happens eventually and until then P holds)
past	$\ominus$	"previous"
	$\ominus^k$	k-times "previous"
	$\boxminus$	"has-always-been"
	$\boxminus_{\leq k}$	bounded "has-always-been" (within last k time steps)
	$\Diamond$	"once"
	$\Diamond_{\leq k}$	bounded "once" (within last k time steps)
	$P \,\mathcal{S}\, Q$	"since" (Q happened before and since then P holds)

Overview on temporal logic operators



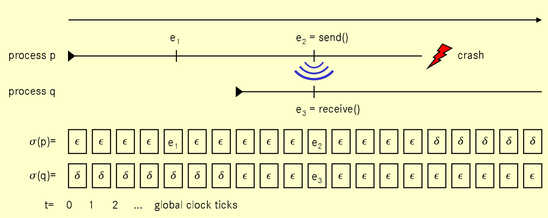
Layered architecture of process

Distributed System Model

- Infinite set of processes with IDs in $\mathbb{N}$ (one process per host per vehicle)
- Linear global time T in discrete steps isomorphic to $\mathbb{N}$
- Processes move in time and space and know their own location λ
- Processes perform events from set S or null event ϵ if idle
- Processes may start at t > 0 and crash permanently (modeled with dead event δ)
- Number of concurrently active processes always finite
- Links prone to send and receive omission failures F_σ
- Processes repeatedly send out heartbeat messages every Δt_{hb} clock ticks

Definition (Global Event History). *The global event history σ describes the sequences of events that every possible process executes over time. Formally,*

$$\sigma : \mathbb{N} \to S \cup \{\delta, \epsilon\}$$
$$p \mapsto \sigma(p) := \begin{cases} \delta & \text{if } p \text{ is inactive} \\ \epsilon & \text{if } p \text{ is idle} \\ e \in S & \text{if } p \text{ performs event } e \end{cases}$$



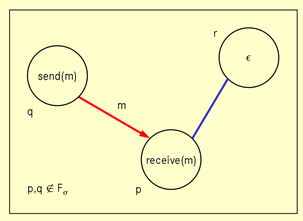
Example of global event history with two processes

Property (Causal Communication). *A triple $(\sigma, \lambda, F_\sigma)$ of global event and location histories and link failures exhibits the causal communication property iff a message at a process p is received if it is sent by only one other process q in vicinity. Formally,*

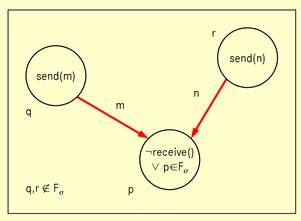
$$\forall p \in \mathbb{N} : \sigma(p) = \textit{receive}(\cdot) \wedge p \notin F_\sigma \Rightarrow \exists q \in N_p : \sigma(q) = \textit{send}(\cdot) \wedge q \notin F_\sigma \wedge \forall n \in N_p : n = q \vee \sigma(n) \neq \textit{send}() \vee n \in F_\sigma$$

- q sends message
- no send omission failure at q
- q is the only sending and not failing process in p's vicinity

snapshot of causal communication



snapshot of packet collision



Heartbeat Mechanism

Definition (Newly Connected). *A process q is newly connected to a process p at time t iff p receives a heartbeat from q at time t and has not received a heartbeat at $t - \Delta t_{hb}$. Formally,*

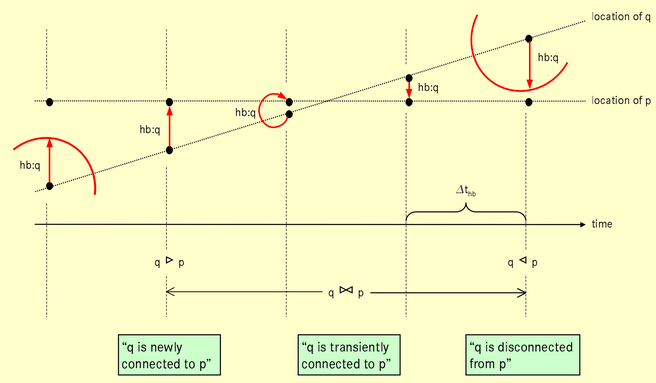
$$\forall p, q \in \mathbb{N} : \triangleright \subseteq \mathbb{N} \times \mathbb{N}$$
$$q \triangleright p :\Leftrightarrow \mathit{hbrcv}(p, q) \wedge \neg \ominus^{\Delta t_{hb}} \mathit{hbrcv}(p, q)$$

Definition (Disconnected). *A process q is disconnected from a process q at time t iff p received a heartbeat from q at time $t - \Delta t_{hb}$ but did not receive a heartbeat from q until t. Formally,*

$$\forall p, q \in \mathbb{N} : \triangleleft \subseteq \mathbb{N} \times \mathbb{N}$$
$$q \triangleleft p :\Leftrightarrow \neg \mathit{hbrcv}(p, q) \wedge \ominus^{\Delta t_{hb}} \mathit{hbrcv}(p, q)$$

Definition (Transiently Connected). *A process q is transiently connected to a process p at time t iff q is not disconnected from p since q has been newly connected to p. Formally,*

$$\forall p, q \in \mathbb{N} : \bowtie \subseteq \mathbb{N} \times \mathbb{N}$$
$$q \bowtie p :\Leftrightarrow (\neg q \triangleleft p) \,\mathcal{S}\, (q \triangleright p)$$



Example on heartbeats from process p's perspective

Neighborhood Service (NHS)

NHS 1 (New Neighbors). *If a process q is newly connected to a process p at time t then p performs at least once a list_chg() event within the next Δt_{hb} time steps. Formally,*

$$\forall p, q \in \mathbb{N} : q \triangleright p \Rightarrow \Diamond_{\leq \Delta t_{hb}-1} \sigma(p) = \textit{list_chg}()$$

NHS 2 (Leaving Neighbors). *If a process q is disconnected from a process p at time t then p performs at least once a list_chg() event within the next Δt_{hb} time steps. Formally,*

$$\forall p, q \in \mathbb{N} : q \triangleleft p \Rightarrow \Diamond_{\leq \Delta t_{hb}-1} \sigma(p) = \textit{list_chg}()$$

NHS 3 (Accuracy). *If a process p installs a list by performing a list_chg() event at time t and q is transiently connected to a process p then the installed list includes q. Formally,*

$$\forall p, q \in \mathbb{N} : \sigma(p) = \textit{list_chg}() \wedge q \bowtie p \Rightarrow q \in \mathit{list}(p)$$

NHS 4 (Completeness). *If a process p installs a list by performing a list_chg() event at time t and q is not transiently connected to a process p then the installed list never includes q. Formally,*

$$\forall p, q \in \mathbb{N} : \sigma(p) = \textit{list_chg}() \wedge \neg q \bowtie p \Rightarrow q \notin \mathit{list}(p)$$

Localized Group Membership Service (LGMS)

LGM 1 (View Integrity). *(i) Every view installed at a member process p includes the process itself. Formally,*

$$\forall p \in \mathbb{N} : \mathit{member}(p) \wedge \sigma(p) = \textit{view_chg}() \Rightarrow p \in \mathit{view}(p)$$

(ii) Every view installed at a non-member process p is empty. Formally,

$$\forall p \in \mathbb{N} : \neg \mathit{member}(p) \wedge \sigma(p) = \textit{view_chg}() \Rightarrow \mathit{view}(p) = \emptyset$$

LGM 2 (Limit on Neighborhood). *Only neighbors are part of a view installed at a member process p. Formally,*

$$\forall p \in \mathbb{N} : \mathit{member}(p) \wedge \sigma(p) = \textit{view_chg}() \Rightarrow \mathit{view}(p) \subseteq \mathit{list}(p) \cup \{p\}$$

LGM 3 (View Accuracy). *If a member process p has a neighbor process q in its list from whom p receives a positive message regarding the membership, then the next view installed at p includes q if p is still a member. Formally,*

$$\forall p \in \mathbb{N} : \mathit{member}(p) \wedge \sigma(p) \in \{\textit{receive(req:q)}, \textit{receive(in:q)}\} \wedge q \in \mathit{list}(p) \Rightarrow (\sigma(p) \neq \textit{view_chg}()) \,\mathcal{U}\, [\sigma(p) = \textit{view_chg}() \wedge (q \in \mathit{view}(p) \vee \neg \mathit{member}(p))]$$

LGM 4 (View Completeness). *If a member process p has a neighbor process q in its list from whom p receives a negative message regarding the membership, then the next view installed at p excludes q. Formally,*

$$\forall p \in \mathbb{N} : \mathit{member}(p) \wedge \sigma(p) \in \{\textit{receive(out:q)}\} \wedge q \in \mathit{list}(p) \Rightarrow (\sigma(p) \neq \textit{view_chg}()) \,\mathcal{U}\, (\sigma(p) = \textit{view_chg}() \wedge q \notin \mathit{view}(p))$$

LGM 5 (View Installation). *Every process p that performs an ingoing event e from the set of join(), leave() and list_chg() at time t, also performs a view_chg() event after t. Formally,*

$$\forall p \in \mathbb{N} : \sigma(p, t) \in \{\textit{join}(), \textit{leave}(), \textit{list_chg}()\} \Rightarrow \Diamond \sigma(p) = \textit{view_chg}()$$

Some Thoughts on Impossibility

System model cannot guarantee NHS and LGMS due to possibly pathologic executions and crash failures! Thus, for a benign system model require...

- Fairness of communication ("Most of the messages are received.")
- Criticality of heartbeat rate Δt_{hb} ("Enough time in between to agree on local membership.")
- Stability of location ("Hosts are connected long enough to exchange some heartbeats.")

Then, we want to prove that a given implementation of NHS and LGMS in the benign system model is satisfied. With the application to traffic jam classification in mind, we will design a distributed algorithm working on top of the LGMS. Simulations will then show us, how well the system solves the given task.

Linda Briesemeister (FT3/AS)
Alt-Moabit 96a, 10559 Berlin, Germany
phone: +49 (30) 399 82 - 286
fax: +49 (30) 399 82 - 491
linda.briesemeister@daimlerchrysler.com