Un esempio di modellizzazione mediante PN: moDElling MObile NEtworks

Presentazione
- Questa dispensa introduce il tool moDElling MObile NEtworks (DEMONE) con lo scopo di mostrare un'applicazione di modellizzazione mediante Reti di Petri

Introduzione a MANET (1)
- MANET (Mobile Ad-hoc NETwork) indica una tipologia di reti wireless che possono operare senza la necessità di una infrastruttura fisica fissa
  - le comunicazioni tra una sorgente e una destinazione sono stabilite e mantenute dalla cooperazione tra i vari host presenti nella rete
  - ogni host può agire
    • sia come end-point di una comunicazione (mittente/destinatario di msg)
    • che come router di pacchetti

Introduzione a MANET (2)
- Le MANET sono sistemi altamente dinamici, a causa
  - del duplice ruolo ricoperto da ogni host
  - del continuo cambiamento nella topologia della rete,
- Due aspetti della dinamica:
  - dinamica della rete: cambiamento della posizione degli host
  - dinamica del comportamento computazionale di ogni host
Introduzione a MANET (3)

• Le MANET sono applicate per permettere la comunicazione tra
  – squadre di soccorso nel caso di disastri
  – navi durante traversate oceaniche
  – robot
  – sistemi spaziali
  – ...

Introduzione a MANET (4)

• Problemi
  – definizione di protocolli di routing specifici per questo tipo di reti
  – studio delle prestazioni
  – necessità di sincronizzazione
  – analisi della concorrenza
  – ...

Our research

The problem

• There exist several environments for simulating MANET
• Most of them
  – are event-driven simulators, where components synchronization is imposed through an external clock
  – do not allow to formally describe the system, so studying interesting computational properties is harder
Purpose

• Building an environment
  – in which synchronization is established by the internal behaviour of the agents in the mobile system
  – which allows formally modelling MANET
    • Petri Net
    • ASM

The Approach

• Modelling the MANET means describing two different abstraction levels
  – the mobile network level, i.e., the set of communicating agents, their movement and the logical links among them
  – the mobile system level, i.e., the formal description of each communicating agent

• Formal Model:
  – Colored Nested Petri Nets (current release)
  – Abstract State Machine (work in progress)
  – ... (future)

Petri Nets

• PNs model the behavior of each communicating agent
  – each communicating agent is a “system”
• Places are states of the system
  – characterized by specific values of state variables
• Transitions are associated to computational activities, which drive the evolution of the system
The Hierarchical Structure of MANET Model

- Layer 0: MANET PN
- Layer 1:
  - Host PN
  - Communication PN
  - Mobility PN
- Layer 2:
  - Service_1 PN
  - Service_2 PN
  - Routing PN

Architecture

- It includes three main logical components:
  - **Mobile Network editor**: for configuring the MANET (number and features of communicating agents)
  - **Visual XDM (conteXt-sensitive Dialog Model)**: editor for the PN, for modeling the behavior of hosts
  - **Mobile System Simulator**: for simulating the entire system network and executing all PNs

MANET Editor

- PN Editor:
  - Specify computational behavior of communicating agents
  - Implicitly defines mobile system clock
Dynamic Source Routing

- **Initiator** wants to communicate with **Destination**
- If (Dest is a neighbour of Init) OR (a route to Dest is in Init's cache)
  - Communication can start
  - End algorithm
- Init broadcasts **RREQ pck** to neighbours
- Algorithm reiterated until route is found
  - **RREP pck** is sent back to Init

Two Routing Protocols

Rete di Petri DSR
Ad-hoc On demand Distance Vector - AODV

- If a route to Dest is not in Init’s cache AND Dest is not a neighbour of Init
  - RREQ pck is broadcasted to neighbours
  - If a node receiving RREQ is not Dest, neither knows a route to Dest, it
    - updates its info about route to Init
    - updates RREQ with its ID
    - broadcasts the updated RREQ
  - Else it
    - unicasts a RREP pck back to Init

The experimentation

- Purpose: Validating DEMONE as a proper tool for simulating MANET behavior
- Method: Simulating the behavior of two popular routing protocols and comparing the results obtained by DEMONE to findings in literature
  - 1500 simulations of Dynamic Source Routing (DSR) protocol
  - 1500 simulations of Ad-hoc On-demand Distance Vector (AODV) protocol
Experimental Setting

- 3 differently populated mobile networks
  - Low density: 10 hosts
  - Medium density: 20 hosts
  - High density: 30 hosts
- For each host:
  - Transmission range randomly defined at the beginning, and constant for the entire simulation
  - Speed and direction randomly defined at the beginning and randomly re-defined at each clock

Collected Data (1)

- For each protocol, 500 runs for each density
  - Total: 3000 simulations
  - In each run Init and Dest are randomly defined
- Time spent for discovering route to Dest
  - Chronological time: measured in milliseconds
  - Simulation time: measured in number of clock cycles – each PN execution is a clock cycle

Collected Data (2)

- Effectiveness: rate of success in route discovering, measured as the ratio of the total number of successful communication to the total number of trials

Collected Data (3)

- Efficiency of each protocol
  - Path optimality: (length of shortest path) / (length of actual path, discovered by the protocol)
  - Routing overhead for the network: (total number of RREQ and RREP) / (theoretical minimum number of packets required for discovery)
  - Routing overhead for each host: (number of times each host executes computational activities related to route discovery) / (network size)
Research Questions
1. For each metric $M_i$, except of success rate
   - $H_0$: There is not statistically significant difference between $M_i$ values for DSR and AODV
   - $H_1$: There is a statistically significant difference between $M_i$ values for DSR and AODV
2. Rate of success is simply compared in the two protocols
3. Is simulation time able to measure time as well as chronological time?
   - Correlation between the two time metrics in both protocols

Results (1)
- Is there statistical difference between $M_i$ values for DSR and AODV?

<table>
<thead>
<tr>
<th>Metric</th>
<th>10 hosts</th>
<th>20 hosts</th>
<th>30 hosts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronological Time</td>
<td>YES (0,0003)</td>
<td>YES (0,0166)</td>
<td>YES (0,0119)</td>
</tr>
<tr>
<td></td>
<td>(greater for AODV)</td>
<td>(greater for AODV)</td>
<td>(greater for AODV)</td>
</tr>
<tr>
<td>Simulation time</td>
<td>YES (0,0000)</td>
<td>YES (0,0000)</td>
<td>YES (0,0000)</td>
</tr>
<tr>
<td></td>
<td>(greater for AODV)</td>
<td>(greater for AODV)</td>
<td>(greater for AODV)</td>
</tr>
<tr>
<td>Path optimality</td>
<td>NO (0,1580)</td>
<td>YES (0,0001)</td>
<td>YES (0,0004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(greater for AODV)</td>
<td>(greater for AODV)</td>
</tr>
<tr>
<td>Routing overhead (network)</td>
<td>YES (0,0000)</td>
<td>YES (0,0000)</td>
<td>YES (0,0000)</td>
</tr>
<tr>
<td></td>
<td>(greater for AODV)</td>
<td>(greater for AODV)</td>
<td>(greater for AODV)</td>
</tr>
<tr>
<td>Routing overhead (host)</td>
<td>NO (0,9970)</td>
<td>YES (0,0395)</td>
<td>NO (0,9117)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(greater for AODV)</td>
<td></td>
</tr>
</tbody>
</table>

Results (2)
- Effectiveness of the protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>10 hosts</th>
<th>20 hosts</th>
<th>30 hosts</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSR</td>
<td>0,7940</td>
<td>0,5880</td>
<td>0,5800</td>
</tr>
<tr>
<td>AODV</td>
<td>0,9800</td>
<td>0,8960</td>
<td>0,8100</td>
</tr>
</tbody>
</table>

Results (3)
- Is there statistical correlation between chronological time and simulation time?

<table>
<thead>
<tr>
<th>Network Size</th>
<th>DSR</th>
<th>AODV</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 hosts</td>
<td>0,80</td>
<td>0,70</td>
</tr>
<tr>
<td>20 hosts</td>
<td>0,77</td>
<td>0,65</td>
</tr>
<tr>
<td>30 hosts</td>
<td>0,77</td>
<td>0,59</td>
</tr>
</tbody>
</table>
Analysis of Properties

Reachability

• All markings are always reachable
  – all computational activities specified in the model can be executed
  – conditions exist for executing all the components of the algorithms implementing the routing protocols

Boundedness (1)

• If some tokens represent the number of communications currently managed by the MANET, boundedness specifies the maximum number of communications the system is able to process

Boundedness (2)

• PN concerning hosts acting as router is unbound
  – each host can serve as router for indefinite number of communications
• PN concerning hosts acting as end points are 1-bound
  – Each host can start only 1 communication
Liveness
- PNs are **live**
  - each transition in all PNs is contained in at least a path connecting the initial marking to other markings

Conservativeness
- The PNs are not **conservative**
  - Tokens are created/removed depending on the specific activities
  - If tokens represent data packets received and re-sent by intermediate host, then conservativeness can be used for verifying no packet is lost during communication sessions

Reversibility
- The PNs are not **reversible**
  - In case of failure the control is taken by a specific module, for recovering purposes

Conclusions
Findings (1)

• In most cases the two protocols present different behavior
  – AODV is more effective, but it consumes more resources
  – This is confirmed by literature
• The empirical study validates the capability of DEMONE to simulate MANET
  – but DEMONE also allows formal modeling

Findings (2)

• Trends of Simulation time and Chronological time are analogous
• The Simulation time, established by internal behavior is a good indicator of Chronological time
  – even if they cannot be considered in the same way
  – results are encouraging and more analysis will be executed

DEMONE

• Imposes a new view on the synchronization of the system
• Allows
  – formal modelling of MANET, in order to analyse computational behaviour of communicating agents and network
  – simulation of MANET: preliminary results are analogous to results known in literature and obtained with other tools

Current /Future Work

• Simulations with larger network size (50 – 100 hosts)
• Implementation of other models
  – Abstract State Machine
• Analysis of more properties
  – Completeness: is EP reachable from SP?
  – Complexity: max number of path for reaching EP from SP