Improving the Dependability of Mobile Ad-hoc Networks through Formal Reasoning

INFOCOM'06 Poster Session

Martín López-Nores[⋆], David Pereira-Paz[†], José J. Pazos-Arias[⋆], Jorge García-Duque[⋆] and Esther Casquero-Villacorta[⋆]

[⋆] ***Department of Telematics Engineering, University of Vigo***
{mlnores,jose,jgd,esther}@det.uvigo.es

[†] ***DMR Consulting***
david.pereira.paz@dmr-consulting.com

Introduction

The context

- **Mobile ad hoc networks** (MANETs).
  - Highly dynamic computing environments, collectively supported by the hosts they comprise.
  - The hosts collaborate to support complex tasks, each one making use of the *services* provided by the others.

The problem

- The dynamism of a MANET makes it hard to offer guarantees of **service provision**.
  - The applications may suffer disconnections at any time.
- To ensure a certain level of **predictability** (and thus make the services more dependable), the hosts must expose some information about themselves, including:
  - **Services** offered for other hosts to use.
  - **Motion profiles:** characterizations of the intended spatial trajectories against time.
  - **Elasticity properties:** whether the services can be migrated from one host to another, cloned, leased, etc.

Proactive services planning

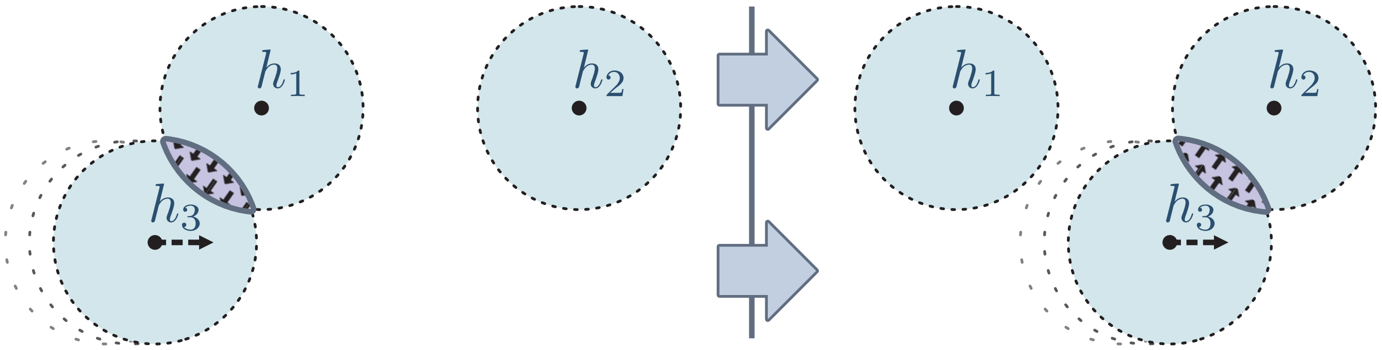
- **Knowledge** allows the hosts to guess how the network is set up at a given moment, and how it will be in the near future.
  - The hosts can find out whether it is possible to satisfy the **service requirements***.
  - In case not, the hosts can take proactive actions to ensure satisfiability.
    - Moving to specific locations,
    - accomplishing service relocations,
    - etc.

* Indications that certain services should be available at specific times and places (can be issued by applications or by human users).

Proactive services planning

Example:

- There is a software agent $\mathcal{A}$ running in host h_1.
- $\mathcal{A}$ needs to use some data stored in host h_2, which is out of communication range.



- Knowing the motion profile of h_3, h_1 finds a **disconnected route** to h_2 through h_3.
- So, h_3 can be used as a relay to take the agent $\mathcal{A}$ from h_1 to h_2; alternatively, $\mathcal{A}$ can access the data on h_2 while the communication ranges of h_2 and h_3 overlap.

Obstacles

- **Uncertainty:** it is unrealistic to assume that a host may have complete knowledge about the MANET.
  - Every host gathers information in a progressive way, from an initial situation when it knows nothing about others.
  - It frequently happens that a host cannot expose complete information about itself (for example, it may not be able to predict its motion profile).
  - Complete knowledge could require managing too much information for the limited computing/memory capabilities of a mobile device.
- **Inconsistencies:** not only partial, the knowledge gathered about the MANET may also be incorrect.
  - The dynamism of the network can make the gathered information stale.
  - There may be malicious hosts publishing erroneous information.
- **Our goal:**
  - To build a framework for *knowledge dissemination and exploitation*...
  - ... endowing the hosts with the ability to reason safely over uncertain and inconsistent knowledge.

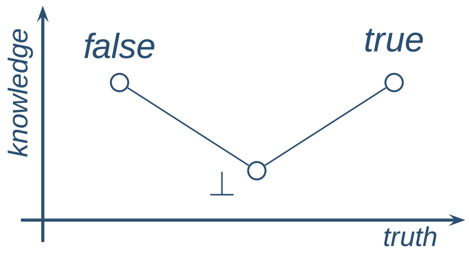
Enabling formalisms

Limitations of Boolean formalisms

- We **cannot** build a solution to reason about MANETs over the classical Boolean logic.
  - It cannot reflect uncertainty (everything is either *true* or *false*), making it possible to mistake for *false* what is indeed *unknown*.
  - It is trivialized in the presence of inconsistencies (the principle of *ex falso quod libet*: anything follows from a contradiction).
- It is necessary to lean on an alternative, more expressive and reliable logic.

Handling uncertainty

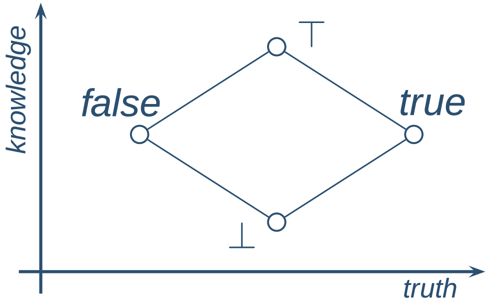
- Kleene's three-valued logic was the first one capable of modeling uncertainty, introducing a new logical value (⊥) to represent the **missing knowledge**.



  - ⊥ lies halfway between the *truth levels* of *false* and *true* (certainly, *unknown* is neither falser than *false*, nor truer than *true*).
  - ⊥ has a *knowledge level* lower than *false* and *true*, meaning that learning new information can turn the *unknown* facts into known ones.
- Applied to a formal modeling of MANETs, Kleene's logic can differentiate what is known to be *true* ("*allowed*", "*possible*", "*reachable*" or "*available*"), what is known to be *false* (meaning the opposite), and what is simply *unknown*.

Handling inconsistencies

- Kleene's logic does not serve to model the **contradictions** that arise when a fact is reported to be both *true* and *false*.
- Belnap's logic introduced a fourth truth value ($\top$) to indicate the facts about which there is contradictory knowledge.



More granularity?

- New logical values can be introduced between $\perp$ and $\{\mathit{false}, \mathit{true}\}$ to identify cases when partial knowledge is enough to obtain certain conclusions.
  - This removes the need to manage complete knowledge bases.
- New values between $\{\mathit{false}, \mathit{true}\}$ and $\top$ can capture levels of agreement when several sources provide contradictory information.
  - Useful to resolve contradictions.
- We must reach a **balance between expressiveness and complexity**.
  - The more logical values, the more complex the reasoning over them.

Outlining a solution

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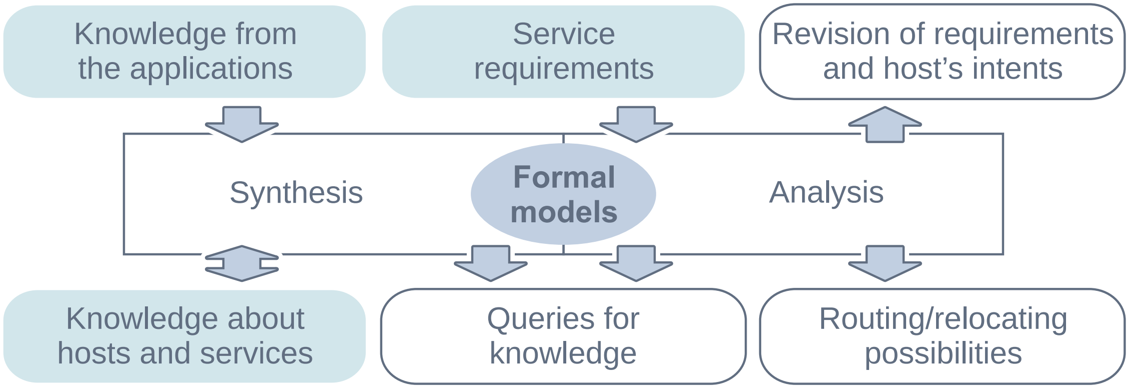
Between the network and application levels

- We are building a layer to reason about service provision in MANETs using **formal modeling techniques**.



- Inputs:
  - **From the application level:** knowledge about the lodging host (intended motion profile, services it plans to provide, etc.)
  - **From the network level:** analogous knowledge about other hosts.
  - **From either source:** knowledge about the impossibility to take certain moves, the fact that a given service can only be provided by certain hosts, the availability of certain services to be migrated or cloned, etc.

Harnessing model-checking

- The **Synthesis** module uses the knowledge to generate formal models that capture what is known about the present and future states of the MANET.
- Over those models, the **Analysis** module checks the satisfiability of the service requirements using model-checking techniques.
  - Model-checking is fully systematic, even with multi-valued logics.
  - Moreover, it is not limited to finding YES/NO responses.
    - If the model-checker finds that a service requirement can be fulfilled, the traces it followed over the formal models provide **routing possibilities**, in form of *direct*, *multihop* or *disconnected* routes.
    - If the requirement cannot be fulfilled, the traces serve to automatically derive **relocation possibilities** involving service migrations, cloning, etc.
    - If the knowledge available does not serve to conclude about the satisfiability of the requirement, it is easy to automatically derive **queries for knowledge**.

Negotiating service requirements

- The **Analysis** module can also suggest revisions of the service requirements:
  - To specify any details left open (related to spatial or temporal conditions)...
  - ... or to recommend changes to the intended plans in case these impeded fulfilling the requirements.
- The suggestions can be accepted, rejected or ignored.
- This mechanism is the basis to implement **policies** by which the hosts can negotiate changes in the MANET to reach the configuration that best satisfies their service requirements.

Work in progress

Work in progress

- We are implementing the approach by borrowing solutions from the incremental development of real-time systems.
- Specifically, from the SCTL/MUS-T methodology.
  - A **six-valued logic** (the first generalization of Kleene's) to model uncertainty, and three additional values to handle inconsistencies.
    - The minimal solution to achieve the advantages of generalizing Kleene's and Belnap's ideas.
  - A sort of **temporal logic** as the language to express the functional requirements of a real-time system.
    - Suitable to exchange knowledge between hosts in a MANET and to enunciate service requirements.
  - **A scenario-like formalism** also available, more accessible for human users.
- Many features of SCTL/MUS-T are readily applicable to reasoning about service provision in MANETs.

Expected results

- A flexible solution to reason **soundly** about service provision in MANETs, which is not possible with Boolean formalisms.
  - Managing uncertainty and inconsistencies.
- The basis for **different policies** to negotiate service requirements and proactively define the best network configuration for their interests.
- **A practical solution** in terms of computational cost.
  - The explicit support to deal with partial knowledge allows each host to tune the amount of information it handles according to its computing and memory capabilities.

End