On the Universal Generation of Mobility Models

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***Abstract*—Mobility models have traditionally been tailored to specific application domains such as human, military, or ad hoc transportation scenarios. This tailored approach often renders a mobility model useless when the application domain changes, and leads to wrong conclusions about the performance of protocols and applications running atop of different domains. In this work, we have proposed and implemented a mobility modeling framework based on the observation that the mobility characteristics of most mobility-based applications can be captured in terms of a few fundamental factors: (1) *Targets*; (2) *Obstacles*; (3) *Dynamic Events*; (4) *Navigation*; (5) *Steering behaviors*; and (6) *Dynamic Behaviors*. Using UMMF we have mapped application-domain-specifics to UMMF elements, demonstrating the power and flexibility of our approach by capturing representative mobility models with good accuracy in terms of a large number of topological metrics.**

I. Introduction

There is an imperative need of mobility models that are representative of the application domain scenarios associated with them. There are two main paths to meeting such a need: (1) the *Model-to-Trace* approach, corresponding to the *mathematical* modeling of the mobility characteristics of certain scenarios; and (2) the *Trace-to-Model* approach, consisting of measuring mobility traces from actual applications, characterizing them, and then designing mobility models derived from such characterizations. The work in this paper focuses on the former approach, but also addresses issues that impact the advancement of the *Trace-to-Model* approach.

Modeling new application scenarios usually entails either the creation of new models from scratch, or the mapping of such scenarios to general mobility models (e.g. Random Waypoint (RWP) [1], Reference Point Group Mobility (RPGM) [2]). This reality makes it difficult to comprehensively assess the performance and correctness of new protocols and algorithms for mobile networks. In this work, we introduce *UMMF: a Universal Mobility Modeling Framework* based on the observation that the mobility characteristics of most mobility-based applications can be captured in terms of a relatively small set of fundamental factors, or mobility building blocks (see below).

The research of Medina and Basu was sponsored in part by the U.S. Army Research Laboratory and the U.K. Ministry of Defence and was accomplished under Agreement #W911NF-06-3-0001. The views and conclusions contained in this document are those of the author(s) and should not be interpreted as representing the official policies, either expressed or implied, of the U.S. Army Research Laboratory, the U.S. Government, the U.K. Ministry of Defence or the U.K. Government. The U.S. and U.K. Governments are authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon. Basu also received partial support from the Army Research Laboratory under Cooperative Agreement Number W911NF-09-2-0053. The work of Gursun and Matta was partially supported by NSF CISE/CCF #0820138 and CISE/CSR #0720604.

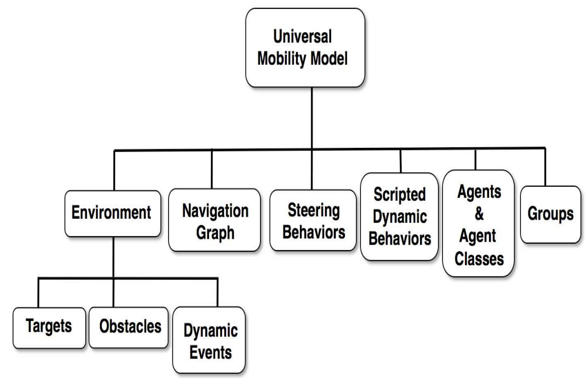

Fig. 1. Hierarchy of Elements Conforming a UMMF-based Mobility Model

The advantages offered by the UMMF framework are manifold: (1) better modeling realism; 2) reproducibility of research results; (3) enabling vof basic research on dynamic topologies, MANETs, and other intrinsically mobile application scenarios; and (4) aiding the development of techniques to translate real mobility traces to accurate synthetic mobility models. The contributions of this work fall in all the above categories, and therefore we argue that UMMF will play a fundamental role in advancing the state-of-the-art of mobility-related research and applications.

II. UMMF: A Universal Mobility Modeling Framework

UMMF enables the *universal* generation of mobility models, based on the observation that the mobility characteristics of most mobility-based applications can be captured in terms of a relatively small number of fundamental factors: (1) *Targets*; (2) *Obstacles*; (3) *Dynamic events*; (4) *Navigation*; (5) *Steering behaviors*; and (6) *Dynamic Behaviors*. UMMF-based models are formed by *composing* subsets of such fundamental mobility building blocks.

Figure 1 depicts a hierarchical diagram of the elements comprising a UMMF-based mobility model including: (a) a model environment, which encompasses the modeled *geographical plane*, *targets*, *target sets*, *obstacles*, and *dynamic events*; (b) a *navigation graph* enabling the navigation capabilities of mobile agents; (c) a set of *steering behaviors*, which can be

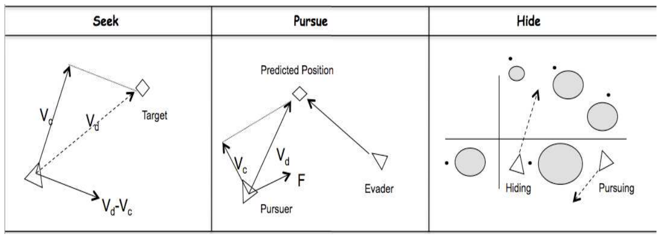

Fig. 2. Individual Steering Forces

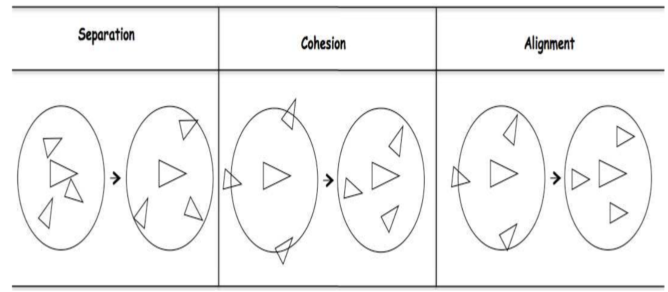

Fig. 3. Combination of Individual Steering Forces to achieve flocking

applied individually or in combination to capture the notion of physical forces underlying observed mobility patterns with different levels of complexity; and (d) *scripted dynamic behaviors*, enabling the user to influence the execution of mobility models. In addition to these elements, UMMF-based models define *mobile agents* classified into agent classes with specific properties, and group specifications dictating how the defined mobile agents relate to each other. Agents and groups of agents interact not only among themselves but also with the other UMMF building blocks. UMMF encompasses the following main elements:

- **Environment**. A simulated geographical area divided into *cells*, in which all UMMF building blocks are placed and dimensioned.
- **Targets**: Elements associated with the mobility objectives of agents and groups (i.e. destinations, mission goals). Targets can be selected implicitly or explicitly.
- **Obstacles**: Elements capturing the semantics of environment elements constraining the movement of agents.
- **Dynamic Events**. Elements modeling of two types of general dynamic events. One corresponds to events taking place at specified or pseudo-randomly chosen times; and the other corresponds to *dynamic obstacles*, which emerge in time like dynamic events and effectively obstruct or invalidate plane areas.
- **Navigation Graphs**. Graphs where nodes represent geographical locations, and edges representing the adjacencies between them. Used for implementing the path planning aspects of a mobility model.
- **Steering-behaviors**. UMMF uses Steering Behaviors acting as *attraction* and *repulsion* forces, effectively enabling agents to react to the relationship between themselves and other agents, and the environment. Table I summarizes the steering forces used in our framework.

  Figure 2 shows some examples of individual steering behaviors, while Figure 3 shows an example of the combination of individual steering forces at a group of nodes to achieve a more complex *emergent* group behavior known as *flocking*. Note that the composition of the Pursuit, Separation, Cohesion, and Alignment steering behaviors generates *correlated mobility models*.
- **Agents, Agent Classes, and Groups**. The specification of mobile agents is based on the notion of groups. Mobility scenarios entailing a set of nodes operating without group constraints (i.e. RWP), are captured in UMMF by having a single group with no leader.
- **Dynamic Behavior Specification**. Events that may take place at any given time and may cause the alteration of the rules governing the movement of agents, invalidate subgraphs of the navigation graph, and change the properties of the terrain in the surrounding areas.

III. Execution of a Universal Model

The execution flow of a UMMF-based mobility model is divided into three main stages: (1) Node placement and interconnection; (2) Topology evolution; and (3) Generation and channeling of mobility-related traces. The main aspects in an UMMF model execution flow are the following:

- **Node Placement**. In the current UMMF implementation nodes are initially placed randomly across the model environment/plane. Extending UMMF to include different node placement strategies is straightforward.
- **Network Connectivity**. Nodes are placed and interconnected at the beginning of a model execution, and thereafter connectivity is recalculated at parametrized fixed intervals (e.g. one second).
- **Periodic Events**. UMMF defines a *Snapshot parameter*, dictating the periodicity in which snapshots of the dynamic topology will be taken. Upon the occurrence of a snapshot event the following tasks are preformed: (1) Updating the positions of all nodes; (2) checking which nodes arrived to their targets, and set them to perform their next task; (3) updating the topology configuration; and (4) computing a set of topological statistics associated with the newly formed topology.
- **Dynamic Events**. Events that can take place at arbitrary times during a model execution, and may have associated with them specific scripted behaviors to be invoked by the function that handles them (Dynamic Event Handler).

IV. UMMF Interfaces

UMMF provides data interfaces with: (1) a dynamic visualization tool (e.g., a custom-developed tool called *VizTools*); (2) a simulation environment (OPNET [4], NS [5] etc.); (3) data analysis tools; and (4) a dynamic scripting environment (i.e. *Lua* [3]), enabling the direct influence of the modeler on the execution of a UMMF-based model.

Figure 4 depicts the elements involved in the specification and generation of UMMF models: (a) a *semantic characterization* of the mobility patterns associated to the given application domain scenario; (b) a *XML-based configuration* file mapping

TABLE I
STEERING BEHAVIORS

Type	Behavior	Steering Force Description
Individual Behaviors	Seek	*Attraction force* that draws an agent to a particular target.
	Flee	*Repelling force* that causes an agent to move away from a given geographical location.
	Arrive	*Attraction force* that enables agents to halt their movement upon reaching a target.
	Pursuit	*Attraction force* that is employed in cases where a mobile agent is expected to intersect another agent or any moving element.
	Hide	*Repulsion force* that causes an agent to position itself so that an obstacle is located always between itself and the line of sight of another agent/enemy.
	Evade	*Repulsion force* that enables agents to move towards the opposite direction of an expected intersection with another node.
	Wander	*Attraction force* that causes an agent to behave as a random walker.
	Obstacle and Wall Avoidance	*Repulsion forces* that enable agents to avoid (1) dynamic obstacles as they are encountered on path traversals, and (2) walls.
Group Behaviors	Alignment	*Attraction force* that keeps an agent aligned with respect to others in its group.
	Separation	*Repulsion force* that separates an agent from the others in its group.
	Cohesion	*Attraction force* that causes an agent to move towards the center of mass of its neighborhood.
	Flocking	Combination of *separation*, *alignment*, and *cohesion*.

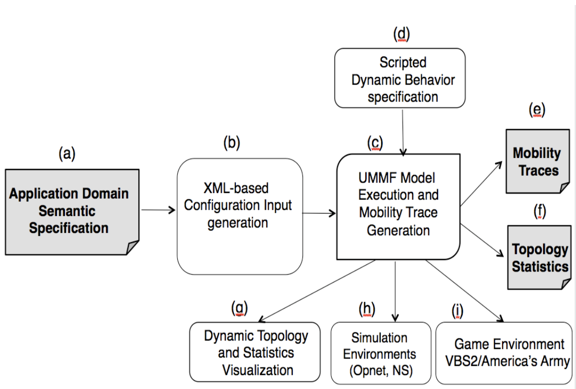

Fig. 4. High-Level UMMF Flow Diagram.

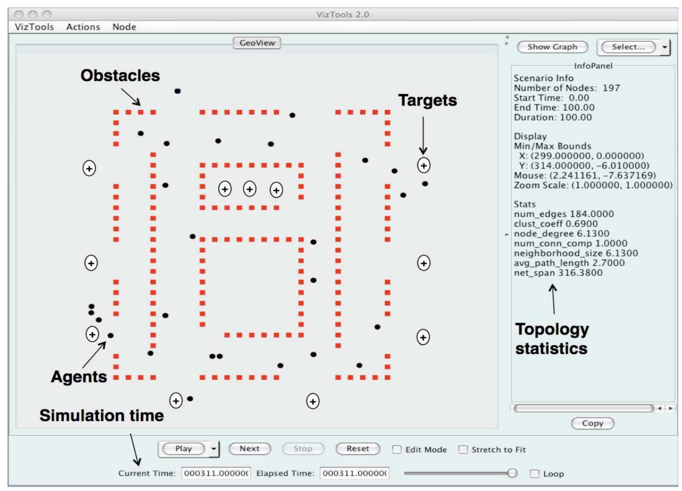

Fig. 5. VizTools snapshot view of Manhattan model execution

the semantic characterization of the model to a combination of UMMF components; (c) a model execution, which implements all the UMMF elements described in Section II; (d) a *scripted specification* of dynamic behaviors provided by the user; and a set of UMMF data-based interfaces in the context of (e) *mobility traces*; (f) time-series of topology statistics; (g) *dynamic topology visualization*; (h) *simulation environments*; and (i) *game and other virtual reality environments*.

V. Application Domain Scenarios

We have succesfully used UMMF for capturing both, "generic" models such as RWP and RPGM, as well as models that are tailor-made for specific application domain scenarios. Some examples are:

A. Manhattan Model

The *Manhattan mobility model* was proposed for the study of *Vehicular Ad hoc networks (VANETS)*, seeking to capture the movement of vehicles/agents within an urban area. Figure 5 shows a VizTools view of this scenario modeled in UMMF.

B. Message Ferries

Model introduced in [6] as a mobility model for *Store-Carry-and-Forward* scenarios, where nodes relay data to other nodes as they move around, storing messages until they can be delivered. Two types of nodes are defined: (1) regular nodes, and (2) message ferries. Regular nodes can be static or mobile; message ferries are intended to visit regular nodes according to some routing specification with the purpose of getting and delivering data messages from and to them. This mobility scenario has a wide variety of applications, and research for specific domains involves the design and analysis of route layouts for the message ferries.

C. Military Mobility Scenarios

We modeled in UMMF, a military exercise scenario carried out in Lakehurst, New Jersey. The scenario consisted of a set of military convoys carrying out the mission of leaving their base and traversing a series of scattered checkpoints. During the exercise, a series of simulated bombs are detonated, effectively disabling some of the checkpoints, and causing the agents forming the convoys to scatter and regroup, and subsequently adapt their routing path to avoid disabled checkpoints.

VI. Conclusions and Future Work

We have introduced a *Universal Mobility Modeling Framework (UMMF)*, which is based on the observation that most mobility scenarios, simple or complex, can be effectively decomposed into a sound set of *mobility building blocks*.

Many fertile areas of research are enabled by UMMF, but still many future work areas remain open: (a) adding further geographical data; (b) realistic signal propagation models; (c) expansion of UMMF interfaces; (d) automatic parameter generation, and parameter range calibration; (f) integration of UMMF with game and virtual environments; and (g) pursuing UMMF-enabled basic research in the context of dynamic topologies.

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