Chapter 4

Modeling mobility

In this chapter, I develop a system model for the mobility event by incorporating the state transitions associated with the basic operations that take place during handoff. The system model decomposes a mobility event into various tasks and subtasks and analyzes the primitive operations.

4.1 Summary of key contribution and indicative results

In the absence of any formal mechanism to analyze the dynamics of handoff systems, it is difficult to predict or verify the systems performance of un-optimized handover or any specific handoff optimization technique. Without an existing mobility system model, it is difficult to design a new mobility protocol or design new optimization techniques of an existing mobility protocol in a systematic way.

I model the handoff-related processes as Discrete Event Dynamic Systems (DEDS) [CH90] and use Deterministic Timed Transition Petri Net (DTTPN) to build various un-optimized mobility models and their associated optimization techniques. I perform data dependency analysis and resource analysis of the handoff related operations to determine the possible sequence of operations and investigate behavioral properties such as deadlocks and liveness associated with the handoff operations using Petri net.
My proposed framework for the mobility model has the following key features:

- My proposed mechanism analyzes data dependency among the handover components and illustrates how handoff operations are distributed over the network components at different layers.

- Investigates resource dependency analysis of various handoff operations from an experimental testbed.

- Design a mobility system model using Timed Transition Petri net based on data dependency analysis and resource dependency.

Key benefits of the mobility model are as follows:

- The model can predict systems performance for optimized handoff operations.

- The model can design optimal path for sequence of execution of events based on expected performance and resource constraints.

- The model can verify systems behavior (e.g., deadlocks) during handover.

- Design of various Petri net-based approaches (e.g., Floyd algorithm, RTP-based, Matrix-based solution) to evaluate the mobility models for different handoff components.

- This system model can investigate parallelism and opportunity for optimization during a handoff operation. Using these models one can predict or verify the systems performance of an un-optimized handover or any specific handoff optimization technique.

- This model can predict the performance of any mobility protocol under any specific deployment scenario, such as intra-domain, inter-domain and heterogeneous handoff.
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The model can also analyze the trade-off between performance metrics and resources when a mobility event exhibits parallel, optimistic or speculative operations.

In the rest of the chapter, I discuss the related work, dynamics of the proposed Petri net based mobility model, detail mechanisms to evaluate the systems performance and investigate the opportunity for optimization using the model-based approach.

4.2 Introduction

Behavioral properties of any system are those properties that characterize the interaction among different components of the system. These properties define how the systems operate under varying working procedures. In order to understand the dynamic behavioral properties of the handoff system, study the interaction among the primitive operations of handoff, and investigate the trade-off between the performance metrics such as handoff delays and resource utilization during the handoff operations, it is important to design a formal mobility system model. For example, some of the questions related to systems dynamics could be things like - Will the system ever reach a conflict state under a given sequence of handoff operations where one operation cannot proceed because other operation has not started yet?; Under what conditions will there be a conflict due to resource sharing?; How does the system behave in the absence of conflicts; Can we obtain required performance measures for the system under some resource constraints? The model should also be useful to define the control aspects of the above system that can provide certain guidance to rectify a certain anomaly, unwanted behavior such as deadlocks. Non-availability of data and resources due to sharing could lead to possible deadlock situations that should be avoided by scheduling the handoff operations properly. This model can analyze the important behavioral system properties of the mobility event, such as possible deadlocks during handoff operations.
the loss of data at the expense of additional bandwidth resources.

### 4.12.2 Opportunity for proactive operation

In some cases, where parallel operations among the handoff processes are not possible, many of the operations can be completed proactively. Proactive operations means, some of the handoff related operations can be done in the current network before the mobile moves to the new network. Network discovery, IP address acquisition process, and authentication processes are some of the handoff related operations that can be performed ahead of time in the serving network before the mobile moves to the new network. However, additional resources are needed to support these proactive operations. I will describe many of the proactive mechanisms for handoff in Chapter 5.

### 4.13 Concluding remarks

Based on the data dependency, resource analysis for different handoff operations it is possible to build a mobility model using Timed Transition Petri net for both optimized and un-optimized handoff systems. Using the hierarchical approach of Petri net, each of the handoff components can be modeled independently based on the primitive operations associated with the respective handoff component. For example, handoff component such as layer 3 configuration is based on several layer 3 primitive operations namely, IP address acquisition, duplicate address detection and address resolution. Petri net models for each of these handoff components (e.g., discovery, configuration) can be synthesized to build the complete handoff system. Depending upon the types of handoff and whether one would like to investigate the systems performance (e.g., cycle time) or check the anomaly of the handoff system (e.g., deadlocks), one can apply a specific Petri net based methodology. For example, in order to verify the systems performance one can use Floyd algorithm approach, in order to determine the exact
cycle time, one can use circuit-timed based approach.

On the other hand if one needs to determine the system anomaly such as deadlocks, one would need to determine that using reachability analysis. By investigating the Petri net model for un-optimized handoff system one can determine the opportunity for parallelism whereby some of the handoff related operations could run in parallel, but this parallel operations will need some modifications of the behavior of the current systems. For example, having the ability to discover layer 3 point of attachment (default router) during the discovery of layer 2 point of attachment (access point), one would need to modify the layer 2 beacon so that it can carry router’s address or the subnet prefix. Thus, a mobility model can help analyze the performance of the existing handoff systems while it also offers the ability to predict the behavior of the new systems that can be designed based on the available resources and expected systems performance.