Chapter 10

Conclusions and future work

In this chapter, I discuss some of the general principles of mobility optimization that I inferred during the course of my thesis, highlight the main contribution of my thesis and potential future work that can be carried out.

10.1 General principles of mobility optimization

Currently, there are many mobility protocols available, each with its own strength and weaknesses. Each of these mobility protocols has historically evolved its own optimization techniques without regards for any generic framework. Thus, it is desirable to have a set of guidelines for the protocol designers, mobile users and architects who plan to use these mobility protocols and associated optimization techniques based on their usage requirement and applicability. In this section, I summarize the fundamental parts and factors that drive the systems optimization and describe the fundamental principles of systems optimization for mobility management. Some of these are protocol design methodologies and some are guidelines for any service provider or enterprise that may like to deploy these mobility protocols and relevant optimization techniques.
1. Since current mobility protocols and the associated optimization techniques are ad hoc in nature, it is useful to have a systematic analysis of the mobility event while designing the appropriate optimization techniques.

2. Since the mobility involves various layers of the protocol stack, it is important to discover the type of mobility the mobile will be subjected to, such as layer 2, layer 3 or application layer. Type of mobility will be determined based on mobile node’s mobility pattern, such as cell handoff, subnet handoff or domain handoff, type of application supported on the mobile node, type of access network.

3. Since layer 2 handoff optimization techniques are access dependent, it is important to consider the access characteristics of each network, such as channel access algorithm (e.g., CSMA/CA, OFDM, TDMA). For example, CDMA network will have different access characteristics than 802.11 networks. Amounts of resources used (e.g., channel bandwidth) will vary based on the types of access networks.

4. Each mobility event (e.g., handoff) can be considered to consist of a set of abstract functions, such as discovery, configuration, authentication, security association, registration, binding update and media delivery. Optimization of these abstract functions can take place independent of each other but often benefit from cross layer triggers.

5. A mobility event can be considered as a discrete event dynamic system (DEDS), where each of these abstract functions can be considered as a specific discrete event. Optimizing each of the discrete events can contribute to the overall systems optimization.

6. Scheduling of the primitive functions that are part of these handoff events plays an important role in the overall systems behavior including systems performance and resource usage.
7. Scheduling of the handoff primitives needs to take into account the data dependency among the abstract operations. Data dependency will determine the extent of parallelism that is possible during the handoff operations.

8. Deadlocks need to be avoided during any mobility operation. Deadlocks are typically caused by lack of data from previous primitive operations or lack of available resources needed for an operation. Thus, the scheduling of the primitive events should ensure that there are enough resources available for any kind of parallel or speculative operations and there is availability of data.

9. It is important to consider the transport type (e.g., RTP, TCP) supported by an application running on the mobile when it is subjected to handoff as each of these applications has a different performance requirement in terms of packet loss, delay and jitter.

10. Since there are several mobility protocols available and each of the mobility protocols is suitable for a specific type of application (e.g., RTP- and TCP-based transport) and specific mobility pattern (e.g., layer 2 handoff, layer 3 handoff, inter-domain handoff) a policy-based mobility management scheme can be appropriate in many cases.

11. Since the primitive handoff operations in each layer take place independent of the operations in other layers, cross-layer triggers from lower layers help to expedite the handoff operations in upper layers. Thus, any optimization framework needs to apply any of the available cross layer optimization techniques. IEEE 802.21 has defined one such media independent handover function that provides cross layer triggers to expedite the handover.

12. It is always useful to have a handoff model that can predict the systems performance based on the schedules and available systems resources. By varying different systems parameters and resource availability, performance of the system will also vary.
Service providers can use the handoff model to determine the type of protocol and optimization technique needed for a specific scenario.

13. Scheduling of handoff primitives will be largely determined by the systems resources and data dependency among the events. Since scheduling of handoff primitives affects the systems performance and it can be changed to meet the performance requirements at the cost of added systems resources.

14. Scheduling of the handoff operations can also affect the trade-off between the resources expensed (e.g., battery, CPU, bandwidth) and systems performance (e.g., delay, packet loss). Thus, the types of optimization are largely determined by the extent of trade-off that can be allowed.

15. In case of multi-interface mobility, a make-before-break mechanism helps to reduce the delay and packet loss at the expense of additional resources\(^1\), since both the interfaces remain active during handoff. The extent of overlapping operations will be determined by the amount of resources that could be expensed during handoff.

16. Proactive operations appear to be most attractive to provide the desired handoff performance (e.g., delay and packet loss) compared to sequential and parallel operations. However, there is a trade-off between amount of resources and performance in case of multiple target networks, since the mobile needs to complete proactive handoff related operations with multiple target networks to increase the probability of successful handover.

### 10.2 Summary of contribution

This thesis contributes to the general theory of optimized handover. Some of the key contributions include identification of basic properties of a mobility event, formulation of a

\(^1\)Resources are defined in Appendix C
CHAPTER 10. CONCLUSIONS AND FUTURE WORK

mobility systems model, design of optimization techniques based on some fundamental
design principles of optimization and evaluation of the associated optimization techniques
by means of analysis, model-based simulation, and experiments. These contribution can be
summarized in following three main areas.

First, this thesis has addressed the need for a formal systems model that can characterize
a mobility event and the associated mobility optimization methodologies. It provides a
systematic and formal approach to a mobility event that works independent of the type
of mobility protocol. After a thorough analysis of the abstract operations associated with
several mobility protocols, I determined that these basic operations form a set of discrete
events that can be modeled as discrete event dynamic system (DEDS). I used deterministic
timed transition petri net (DTTPN) to model the mobility event and analyzed its behavioral
properties and systems performance. This model has the ability to predict the systems
performance based on the availability of the systems resources and the mobility pattern.
Analysis of this model and the optimization methodologies will help to define a set of
principles and guidelines for designing any new mobility protocol as well as evaluate the
effectiveness of a specific mobility protocol in a deployment scenario.

I have developed the Petri net model that can analyze the behavioral properties such
as deadlocks and validate systems performance of any type of handoff optimization sup-
porting intra-technology, inter-technology, simultaneous mobility and multi-layer mobility.
The model can also perform tradeoff analysis between the handoff performance of these
optimization techniques and systems resources. The model-based approach provides the
ability to define various handoff schedules under resource constraints and can determine
the extent of parallelism and proactive operations that are possible among the handoff com-
ponents.

Second, I have developed a series of optimization techniques (e.g., reactive, proactive
and parallel) for different handoff components and have carried out extensive experiments
to validate these optimization techniques. I have applied these optimization techniques to
different mobility scenarios, such as simultaneous mobility, multi layer mobility and multicast mobility, multi-interface mobility and compared the results with the non-optimized version. These series of experiments provide a systematic methodology that can be carried out in a repetitive manner and can be applied to optimize different handoff components.

Third, I have developed a hierarchical scope-based multicast architecture to support multicast streaming using proxies in the access network. This proposed architecture introduces a novel local advertisement insertion technique and program management between local program and global program. I have developed a few optimization techniques to support fast-handoff for multicast traffic in a hierarchically scope-based environment. These techniques are based on proxy-based proactive triggering and application layer triggering to expedite multicast stream delivery by reducing the “Join” latency.

10.3 Future work

My thesis laid the foundation for the systematic approach to mobility event that can be analyzed by a formal model using Petri net. However, this model-based analysis of mobility event can further be enhanced to make it more useful to the wireless community and mobility deployment. The following is a list of future work items, that I believe could be pursued beyond my thesis work.

1. Although I have used this model to validate few of the mobility optimization techniques, this model can be enhanced to study the behavioral properties and systems performance of any type of mobility protocol, such as transport layer and mobility in other types of networks such as ad hoc networks.

2. Using the current model, I was able to study and detect the behavioral properties such as systems deadlocks, investigate the anomaly of a specific schedule and then compare various schedules, such as proactive, reactive and concurrent. This model can be enhanced so that one can use it in an automated fashion to generate a specific
schedule of the handoff operations given a set of resource constraints, performance objectives and dependence graph. Automatic generation of schedules for handoff operations to meet the desired quality of services under available resources will help to use the right set of protocols.

3. Using the systematic analysis of the mobility functions, one can design a customized mobility protocol suitable to one’s own set of requirements. Currently, any mobility event depends upon a set of protocols each doing its own desired functions (e.g., DHCP for IP address acquisition, server discovery). However, each of these protocols adds additional overhead when used individually. Using this model, one can design a comprehensive mobility protocol that will define its own set of protocols for each of the desired functions instead of using the existing ones.

4. Current Petri net model has looked at the resource parameters of the mobile only. This model can be enhanced to predict the performance based on the resource parameters of all the network elements that are involved in the mobility event. Other system elements may include layer 2 point of attachment (e.g., Access Point), layer 3 point of attachment (e.g., router), and servers in the network. The distributed resource metrics would be useful for any wireless service providers that may like to have an optimized service deployment.

5. The formalization of key techniques, models of systems dependencies and the ability to calculate or predict optimization metrics provide a foundation for the automated discovery and implementation of mobility optimization. I envision specification of the functional components of mobility protocols as defined in Chapter 3 and then having tools that search for application or context specific optimizations, such as caching, proactive, or cross layer techniques.

I plan to pursue some of the future work listed above beyond my thesis defense and apply the results to real life deployment.