1. Identification of fundamental properties that are rebound during a mobility event. Analysis of these properties provides a systematic framework for describing mobility management and the operations that are intrinsic to handover.

2. A model of the handover process that allows to predict performance for both an un-optimized handover and for specific optimization methodologies under resource constraints. This model also allows to study the behavioral properties of the handoff system such as data dependency and deadlocks.

3. A series of optimization methodologies, their experimental evaluation and optimization techniques that can be applied to link, network, and application layers and preserve the user experience by optimizing a handover.

4. Application of model to represent optimizations and comparison of the model-based results against experimental data.

1.1 Definition of Mobility Terms

It is useful to define the mobility related terms that are often used in the context of handover and optimization. In this section, I introduce a few of the related mobility related terms including some of the relevant ones from RFC 3753 [EE04] and ITU-T X.200 [IT04] that are useful for handover optimization and have been used in the rest of the chapters.

**Definition 1** *Mobile Node (MN)* is a node that is capable of changing its point of attachment to the network across layers, namely layer 2, layer 3.

A mobile node may either be a mobile host (no forwarding functionality) or a mobile router (forwarding functionality). A mobile node can have multiple interfaces.

**Definition 2** *Interface identifier* is a unique identifier that is assigned to a specific interface of a node by which it can be addressed for data transfer.
Interface identifier can be a layer 2 identifier or layer 3 identifier depending upon the specific configuration. For example, a MAC address is considered as layer 2 identifier, where as an IP address is a layer 3 identifier.

**Definition 3** *Device identifier* is a unique identifier that is fixed and permanent and is assigned to a device during its manufacturing.

A typical device identifier could be the MAC address of the IP-based device or electronic serial number (ESN) in case of a cellular device.

**Definition 4** *Point of attachment* is the first connection point in the access network through which the mobile node communicates with.

A point-of-attachment can be a layer 2 point of attachment or layer 3 point of attachment. For example, an 802.11 access point or CDMA base station can be defined as a layer 2 point of attachment, where as a router is considered to be a layer 3 point of attachment.

**Definition 5** *Path identification* defines the unique connection path between the mobile and the point of attachment on the network.

A path identifier can be defined as the pair of interface identifiers, where one of them is associated with the mobile and the other one is associated with the network point-of-attachment in the network.

**Definition 6** *Radio Cell* defines a geographical area within which an access point provides radio coverage i.e., where radio communication between a mobile node and the specific access point is possible.

A mobile node uses the radio cell to communicate with the point-of-attachment in the network.

**Definition 7** *A subnet* is a logical group of connected network nodes, where two hosts can communicate through a layer-2 and do not require a layer-3 entity.
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In IP networks, nodes in a subnet share a common network mask (in IPv4) or a network prefix (in IPv6). All hosts within a subnet can be reached in one hop, implying that all hosts in a subnet are connected to the same link.

**Definition 8** An Access Router resides on the edge of an Access Network and connected to one or more access points.

An Access Router offers IP connectivity to Mobile Nodes, acting as a default router to the Mobile Nodes it is currently serving. The Access Router may include functionality beyond a simple forwarding service offered by ordinary IP routers.

**Definition 9** Access Network (AN) is an IP network which includes one or more Access Network Routers.

An access network consists of multiple subnets that could be connected to the same access router or multiple routers.

**Definition 10** Administrative Domain is a collection of networks under the same administrative control and grouped together for administrative purposes.

**Definition 11** Serving Access Router (SAR) is the Access Router that currently offers the connectivity to the MN.

This is usually the point of departure for the MN as it makes its way towards a new Access Router (at which time the Serving Access Router takes the role of the Previous Access Router). There may be several Serving Access Routers serving the Mobile Node at the same time.

**Definition 12** New Access Router (NAR) is the the access router that offers connectivity to the Mobile Node after a handover.
**Definition 13** Previous Access Router (PAR) is an Access Router that offered connectivity to the Mobile Node prior to a handover. This is the Serving Access Router that will cease or has ceased to offer connectivity to the Mobile Node.

**Definition 14** Candidate Access Router (CAR) is an Access Router to which the Mobile Node may do a handoff.

**Definition 15** Anchor MSC is the MSC from which a handover has been initiated.

During a handover in GSM network, the anchor MSC stays in the datapath to help reduce the packet loss in case of handoff forward and handoff backward.

**Definition 16** Target MSC is the MSC toward which a handover should take place.

Target MSC directs base station to assign channel for the mobile that is intended to move to that BS’s radio coverage.

**Definition 17** Handover is the process by which an active MN changes its point of attachment to the network, or when such a change is attempted.

The access network may provide features to minimize the interruptions in progress which is termed as optimized handover. Handover term is often interchanged with handoff.

**Definition 18** Layer 2 handover is a type of handover where the MN changes access points (or some other aspect of radio channel) connected to the same access router’s interface.

This type of handover is transparent to the routing at the IP layer.

**Definition 19** Layer 3 handover is a type of handover where the MN changes access points (or some other aspect of radio channel) connected to different subnetwork interface.

The subnetwork interface may be connected to two different interfaces on the same router or two different routers alltogether. During this type of handover mobile node moves to a topologically new subnet.
Definition 20  *Roaming* is an operator-based term that involves formal agreements between operators that allows a mobile to get connectivity from a foreign network.

Roaming includes the functionality by which the users can send their identity to the local Access Network so that inter-AN agreements can be activated and service and applications in the MN’s home network can be made available to the user in the visited network.

Definition 21  *Systems resources* are resources on the mobile host that are shared by different atomic operations during a handoff event.

These resources could include systems resources such as CPU cycles, battery power and network resources such as bandwidth or channel resources.

Definition 22  *Network resource parameters* are the parameters that are needed to perform different handoff related operations.

These resource parameters could include different wireless parameters such as channel number, frequency, authentication algorithm, authentication server etc. Mobile uses these parameters to carry out the handoff related operations.

Definition 23  *Care-of-Address (CoA)* is an IP address associated with a mobile node while visiting a foreign link; the subnet prefix of this IP address is a foreign subnet prefix.

A packet addressed to the mobile node which arrives at the mobile node’s home network when the mobile node is away from home and has registered a Care-of Address will be forwarded to that address by the Home Agent in the home network.

Definition 24  *Home Address (HoA)* is an IP address assigned to a mobile node, used as the permanent address of the mobile node.

This address is within the mobile node’s home link. Standard IP routing mechanisms will deliver packets destined for a mobile node’s home address to its home link.
**Definition 25** According to ITU-T X.200, *Binding* can be defined as an association when (N)-entities support connectionless-mode by maintaining a binding with the appropriate (N)-SAPs for delivering the connectionless data to the (N+1)-entities.

For example, in case of mobility, a binding can be an association between the temporary Care-of-Address obtained in the visited node and the permanent home address of the mobile node so that the data from the correspondent node can be routed to the mobile node.

**Definition 26** *Encapsulation* is the process of adding control information as the header to any protocol dataframe often for routing purposes. All the overhead and data of that protocol is considered as data after the encapsulation.

IP-IP encapsulation often used in Mobile IP or ESP encapsulation used in IPsec are examples of encapsulation.

**Definition 27** *Home Agent* is a router on a mobile node’s home link with which the mobile node has registered its current care-of-address.

When the mobile node is away from home, the home agent intercepts packets on the home link destined to the mobile node’s home address, encapsulates them and tunnels them to the mobile node’s registered care-of-address.

**Definition 28** *Foreign Agent* is a node on a mobile node’s visited network that intercepts the traffic from the home agent and delivers it to the mobile node connected to the same visited node.

When the mobile node is connected to a visited network, it can use foreign agent as the care-of-address so that packets destined to the mobile node can be captured by the foreign agent and delivered to the mobile node in the visited network.

**Definition 29** *Encapsulation agent* encapsulates the data and sends it to the decapsulation agent that takes out the header and delivers to the target node.
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Home Agent is an encapsulation agent that encapsulates the data traffic using source and destination IP headers and sends it to the Foreign Agent (FA) that delivers the packet to the target node.

**Definition 30** Decapsulation agent communicates with the encapsulation agent and decapsulates the data by stripping the header.

Foreign Agent is a type decapsulation agent that decapsulates the IP-IP tunnel and delivers to the mobile host.

**Definition 31** Binding Update (BU) message indicates a mobile node’s current mobility binding, and in particular its care-of-address.

The mobile can send its binding update either directly to the other communicating node or to the home agent to associate its home address with the care-of-address.

**Definition 32** Tunneling is a process of setting up a point-to-point virtual link between two end points by adding encapsulation header on the data so that it can be routed properly over a tunnel.

Home agent uses tunneling mechanism to send the data from home network to the foreign agent or to the mobile node in the visited network.

**Definition 33** Bidirectional tunnel is a tunnel between two communicating nodes where the data is sent over the tunnel in either direction.

In case of bi-directional tunnel mode operation for MIP, both the home agent and foreign agent act like encapsulation and decapsulation agent.

**Definition 34** Horizontal handover involves mobile nodes moving between access points of the same type (in terms of coverage, data rate and mobility), such as, UMTS to UMTS or 802.11 to 802.11.
A horizontal handover can also be defined as intra-technology handover.

**Definition 35** *Vertical handover* involves mobile nodes moving between access points of different type, such as, UMTS to 802.11 or vice-versa.

A vertical handover can also be defined as Inter-technology handover.

**Definition 36** *Mobile-initiated handover* requires that the MN is the one that makes the initial decision to initiate the handover.

**Definition 37** *Network-initiated handover* requires that the network makes the initial decision to initiate the handover.

**Definition 38** *Handover latency* is the difference between the time a MN is last able to send and/or receive an IP packet by way of the PAR (Previous Access Router), and the time the MN is able to send and/or receive an IP packet through the NAR (Next Access Router).

**Definition 39** *Smooth handover* aims primarily to minimize packet loss, with no explicit concern for additional delays in packet forwarding.

**Definition 40** *Fast handover* aims primarily to minimize handover latency, with no explicit interest in packet loss.

However, minimizing handover latency typically results in reduction of packet loss.

**Definition 41** *Macro mobility* is defined as when a mobile moves between two networks that belong to two different subnets. These subnets may belong to the same administrative domain or different ones.

Layer 3 mobility support and associated address registration procedures are needed when an MN is subjected to macro mobility. Inter-Access Network (AN) handovers typically involve macro-mobility protocols. Mobile-IP can be seen as a means to provide macro mobility solution.
**Definition 42** Micro mobility usually means movement of a terminal within a mobility domain, where a mobility domain maybe confined to a subnet or collection of subnets within an administrative domain.

Micro-mobility protocols exploit the locality of movement by confining movement related changes and signaling to the access network without having the need to interact with Mobile IP. Examples of some well known IP micro mobility architecture include HAWAII (Handoff-aware Wireless access Internet infrastructure), Cellular IP and HMIP (Hierarchical Mobile IP).

**Definition 43** Fast handover aims primarily to minimize packet loss, with no explicit concern for additional delays in packet loss.

**Definition 44** During a Make-before-break handover the MN prepares the new connection path before the old one is broken.

Thus, if the mobile has multiple interfaces, it can communicate with both the old AR and new AR at the same time using either of the interfaces. However, only one interface is used for transmitting data while the other interface is engaged in handover preparation. Alternatively, many of the handover related operations for the second interface can be performed by the first interface. When the mobile has a single interface, a virtual interface is used to make-before-break connectivity.

**Definition 45** During a Break-before-make handover The MN breaks the existing connection before the new connection is made.

In break-before-make handover case, there is an appreciable amount of handover delay as the second interface comes up only after the first interface is disconnected. In case of handover involving single interface the same interface gets configured again in the new network.
**Definition 46**  *Intra-domain handover* refers to a handover scenario where a mobile node’s movement is confined to the domain.

A domain can be defined as an administratve domain, DNS domain or mobility domain anchored by a mobility agent. There are several types of domain defined by [HK89].

**Definition 47**  *Inter-domain handover* refers to a handover scenario where a mobile node moves between two domains.

These two domains can be two different administrative domains, each with its own anchor mobility agent.

**Definition 48**  *Route optimization* is a process of minimizing the data path between the communicating node by having a direct path for data forwarding.

When the mobile node changes its network identifier, data gets rerouted to the new point of attachment and may take a longer route. Route optimization helps to maintain the direct path between the communicating nodes.

**Definition 49**  *Network Assisted, Mobile and Network Controlled (NAMONC)* handoff allows the MN to be involved in an anticipated IP-layer handoff procedure.

The Mobile Node is therefore assisted by the network in performing an anticipated L3 handoff before it completes the L2 handoff.

**Definition 50**  *Network Initiated Mobile Terminated (NIMOT)* handoff allows the network to initiate the handoff and register proactively on behalf of the mobile.

This handoff method enables a rapid establishment of service at the new point of attachment so that the effect of the handoff on real-time applications is minimized.

**Definition 51**  *Network Controlled Handoff (NCHO)* involves the network to handle the necessary RSS measurements and handoff decision.
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NCHO is used in first generation cellular systems such as Advanced Mobile Phone System (AMPS) where the mobile telephone switching office (MTSO) is responsible for overall handoff decision.

**Definition 52** Mobile Assisted Handoff (MAHO) involves the mobile to do RSS measurements and send them periodically to BS.

MAHO is used in Global System for Mobile Communications (GSM), where based on the received measurements, the BS or the mobile switching center (MSC) describes when to handoff.

**Definition 53** Mobile Controlled Handoff (MCHO) MCHO extends the roles of the MS by giving overall control to it.

The MS and BS both, make the necessary measurements and BS sends them to the MS. Then MS decides when to handoff based on the information gained from the BS and itself.

**Definition 54** Join latency is defined as the elapsed time between a host joining the group and the router sending a multicast packet towards the mobile.

A mobile node can send unsolicited join request to the router to trigger the multicast flow failing which it can wait to respond to the router’s query.

**Definition 55** Leave latency is defined as the time between the moment the last host leaves a group and when the routing protocol is notified that there are no more members.

To reduce the leave latency, the last mobile node to leave the group sends group leave message to all router multicast address so that the router prunes the multicast tree. In the absence of specific group leave report from the mobile node e.g., in case of IGMPv1 (Internet Group Management Protocol), the router needs to wait until it does not get any response from any of the clients.