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The MOMBASA Software Environment – A Toolkit for Performance Evaluation of Multicast-Based Mobility Support*

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Abstract. The *MOMBASA Software Environment* is a toolkit that implements mobility-related functionalities complementing multicast protocols for multicast-based mobility support. The functionalities provided by the *MOMBASA Software Environment* include detection of link availability, registration, location update, paging, address translation, handoff initiation, handoff control, rerouting, prevention of handoff oscillation and inactive handoff suppression.
The *MOMBASA Software Environment* is targeted for researchers investigating the support of host mobility in IP-based cellular networks. It aims at performance evaluation of mobility support by means of measurements. The software is easy to maintain, to configure and to extend: a) It has a clear design, b) it provides well-defined configuration and management interfaces, c) policies can be used to control and tune the system behavior and d) it has a generic interface to the multicast which facilitates to investigate multicast protocols of different types.
This paper describes the functionalities, features and structure of the *MOMBASA Software Environment* and presents a framework for evaluating the performance of mobility support using the *MOMBASA Software Environment*. The *MOMBASA Software Environment* is open software under GNU Public License. It is freely available, extensively tested and well documented.

1 Introduction

Performance is one of the key criteria in communication software. Measurement represents an accepted evaluation technique which gives accurate results for certain scenarios. However, measurement-based performance evaluation requires an implementation, at least a prototype. The *MOMBASA Software Environment* provides a prototype implementation for multicast-based mobility support in all-IP cellular networks. As will be explained later, the *MOMBASA Software Environment* is well designed for performance evaluation by means of measurements.

The growing importance of mobile communication deserves support for host mobility in IP-based cellular networks. A general problem of IP networks needs to be solved, which arises from the double meaning of the IP address as a host identifier and as identification of the host's current point of attachment. There exist several solutions for the general mobility problem, the most important approaches are *Address translation and indirect routing* (e.g. Mobile IP [7, 5], RAT [9]) and *Host-based routing* (e.g. Cellular IP [1], HAWAII [8]).

MOMBASA (**MObility support – a Multicast-BASed Approach**) pursues a different approach. The general mobility problem (separation of identity

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and location) is solved by multicast. The main idea of *MOMBASA* is to utilize location-independent addressing and routing to support host mobility which is already provided by multicast. In *MOMBASA*, each mobile is assigned a multicast group address (which is independent of the current network point of attachment). The mobile host subscribes to the multicast group using its current access point to the network. Handoff between access points is performed by multicast operations, namely subscribe/un-subscribe to/from a multicast group. Data packets are distributed via a dynamic multicast tree with branches reaching the current locations of the mobile host while the mobile host roams through the coverage of the cells. The branches of the multicast tree grow and shrink and, hence, follow the mobile's location. In comparison to other mobility approaches, e.g. IETF Mobile IP, MOMBASA has some advantages: *First*, re-routing for handoff is done in the network node where the path to the old and from the new access point diverge (and not in a software agent in the mobile's home network as in the Mobile IP approach which might be distant to the current mobile's location.). *Second*, a *handoff-specific* signaling and infrastructure is in principle not necessary. Instead a multicast infrastructure and protocols – which are expected to exist in future networks – are reused for mobility purposes And *third*, multicast offers inherently mechanisms to minimize the service interruption caused by a handoff between access points.

The *MOMBASA Software Environment* is a toolkit that implements mobility-related functionalities complementing multicast protocols. These functionalities include detection of link availability, registration, location update, paging, address translation, handoff initiation, handoff control, rerouting, prevention of handoff oscillation and suppression of handoff for inactive mobile hosts.

This paper presents the *MOMBASA Software Environment*[1] as a toolkit for measurement-based performance evaluation of mobility mechanisms with different types of multicast. The next section details the implemented functionalities and features. Then the implementation design, configuration and extensibility are described. In the last section, metrics for a performance evaluation are listed.

2 Functionalities and Features of MOMBASA SE

The *MOMBASA SE* implements the following functionalities:

- **Detection of link availability:** Access points advertise their availability on the links they provide service for. Mobile hosts may solicit advertisements from access points.
- **Registration:** A mobile registers with the access point which relays the registration to a gateway. A mobile can be registered indirectly by another access point.
- **Location update:** A mobile host updates its current location with the network.
- **Address translation:** The gateway and the access point perform address translation from unicast to multicast addresses and vice versa. The address translation works either by NAT[2] or tunneling.
- **Handoff initiation:** A handoff can be triggered by the expiration of an advertisement lifetime or a link layer trigger. Alternatively, a handoff can be forced by the network.
- **Handoff control:** Handoff is controlled by the mobile host based on a *handoff request/reply*-scheme. Handoff can be hard, soft or predictive.

[1] In the following abbreviated as *MOMBASA SE*
[2] Network address translation

- **Rerouting:** Rerouting is based on multicast operations. It can be executed in a *break-make* and *make-break* order.[3] Additionally, access points can be added to the multicast tree in advance.
- **Prevention of handoff oscillation:** This prevents a mobile host from being constantly handed over when it is simultaneously reachable by multiple access points.
- **Suppression of handoff for inactive mobile hosts:** Mobile hosts which do not send or receive for a certain duration go into an inactive state and re-register less often. For inactive mobile hosts, the handoff initiation is suppressed.
- **Paging:** Inactive mobile hosts provide the network with uncertain location information. The gateway uses paging to locate these mobile hosts.

Moreover, the *MOMBASA SE* can be characterized by the following features:

- Network components and protocols are based on IP version 4.
- Multicast is used in the wire-line part of the access network. The access point acts as a multicast proxy for the mobile host.
- Minimal modifications to the multicast protocols.
- No modifications to correspondent (fixed) hosts.
- Mobility is supported in the access network.
- Support of heterogeneous access networks, support of handoff between access points providing different wireless technologies (vertical or inter-technology handoff).
- Differentiation between inactive and active mobile hosts.
- Buffering and forwarding of packets for predictive handoff and paging.
- Certain functionalities can be controlled and tuned by policies (handoff type, algorithms for access point selection, paging, buffering and forwarding).
- The system uses soft state, i.e. every state needs to be refreshed or times out.

3 Implementation Design

The main software components of *MOMBASA SE* are: **Mobile Agent (MA)**, **Mobility Enabling Proxy (MEP)** and **Gateway Proxy (GW-P)** which are executed in the mobile host, access point and gateway proxy, respectively. These components complement the multicast routing daemons in the multicast routers. The components are implemented as daemons running in user space. *MOMBASA SE* employs certain design concepts: *First*, it is object-oriented which reduces the complexity of the software. *Second*, all components are based on the same main implementation design. Each implementation has the same basic structure of classes. *Third*, all agents employ an event-driven concept with external and internal events (protocol messages and timer events, respectively).

The *MOMBASA SE* is implemented for Linux systems running on an x86 architecture. Modifications of the Linux standard kernel were necessary for address translation between unicast and multicast addresses and for paging. The software is developed in C++ and uses only standard C and C++ libraries (including the Standard Template Library).

The default configuration of *MOMBASA SE* works with the multicast provided by the standard Linux kernel (IGMPv2 and kernel support for a PIM-SM Version 2 daemon) and a publically available multicast routing daemon for PIM-SM[4] (see [6]). However, the implementation of the MOMBASA SE does not depend on a specific multicast routing daemon (see also the discussion in the next section).

[3] This refers to the sequence of multicast un-subscribe and subscribe operation.
[4] pimd-2.1.0-alpha28

The implementation of *MOMBASA SE* utilizes certain technologies, among others *link-layer (packet) sockets* to intercept packets for buffering, *Linux socket filters* for idle detection, *network address translation* between unicast and multicast addresses and vice versa, and *multi-threading* for buffering.

4 Extensibility

The *MOMBASA Software Environment* is targeted for researchers investigating multicast-based mobility support. While the basic network architecture is assumed to be fixed, the software was designed to become extended in a flexible and easy manner. This includes features for utilization of other multicast types, implementation of enhanced features for mobility support, portability, configuration and testing:

- **Support of multiple multicast types:** The actual version of the *MOMBASA SE* works with IP multicast as it is defined by the standard IP multicast service model in RFC 1112 [2]. The interface to the multicast is provided by IGMPv2 and hence, *MOMBASA SE* supports all multicast routing protocols according RFC 1112 [5]. But *MOMBASA SE* is not limited to these multicast types: Multicast has been the subject of research efforts for the next generation Internet and new schemes have been proposed. Some of them break the standard IP multicast service model. An example is single source multicast, such as PIM-SSM [4]. *MOMBASA SE* is prepared for *Single-source multicast*, its usage requires *IGMPv3* and only minor modifications of the implementation. Moreover, in the next development stage, the *MOMBASA SE* implementation will be extended to support *generic multicast*, where the multicast is regarded as an abstract service for multicast group creation and release, multicast group subscribe and un-subscribe operations and packet delivery. This facilitates the examination of multicast types, which offers interesting features for mobility support (such as third party signaling, sub-casting, etc.) without being limited to IGMPv2/v3 as a multicast group management protocol.
- **Implementation of enhanced features for mobility support:** *MOMBASA SE* has a clear design, detailed documentation about specification and implementation design [12, 14] exists, and it has been extensively tested [15]. Therefore enhanced features can be easily implemented. Moreover, certain system behavior can be controlled and fine-tuned by policies. The software provides hooks for policy handlers to control time and destination of handoff, control buffering and flushing of packets and to retrieve signal quality for handoff trigger. Hence, *MOMBASA SE* ensures that enhanced algorithms can be easily implemented without redesigning major parts. Typical examples for extensions are buffering and flushing strategies and paging algorithms.
- **Portability:** In *MOMBASA SE* only standard libraries are used. This facilitates porting *MOMBASA SE* to other architectures. For example, the mobile agent of the *MOMBASA SE* has been ported to a hand-held PC architecture running with a Linux operating system. This was tested with a *iPAQ* by COMPAQ.
- **Configuration and Testing:** The software is instrumented with capabilities for easy configuration. Management interfaces offer debugging facilities at configurable levels. Moreover, the implementation has been instrumented with testing facilities (such as accessing the actual state, access to databases, etc.)

[5] However, there are multicast routing protocols which are less suitable for mobility support (such as broadcast- and prune protocols, like DVMRP [10]) and some which better meet the requirements of host mobility (such as PIM-SM [3] which is based on a concept of rendezvous points and shared trees).

5 Framework for Performance Evaluation

MOMBASA SE can be used to estimate the performance of multicast-based mobility support. This includes a quantitative evaluation of mobility-related performance metrics and a comparison of selected policies. Moreover, the impact of mobility on transport and application layer can be estimated. Suppose a typical testbed setup as shown in Fig. 1, which basically consists of an access network and an emulated WAN representing the Internet. The gateway executing the *gateway proxy GW-P* and a multicast routing daemon, interconnects the access network with the Internet. Additional components of the access network are multicast routers and access points executing *Mobility Enabling Proxies (MEPs)* and providing service in a wireless cells. A mobile can move freely within the coverage of the cells. This setup represents a typical topology and can be used in various scenarios for different mobility patterns, wireless technologies, workloads, buffer sizes and multicast approaches.

Two types of metrics can be identified: *mobility-related metrics* are general to all multicast approaches. *Multicast-related metrics* refer to a certain multicast approach. Typical mobility-related metrics for performance evaluation are:

- Handoff and rerouting latency,
- Throughput and packet loss caused by handoff,
- Sequence of packet delivery,
- Signaling overhead for handoff,
- TCP-specific parameters (window size, sequence numbers, retransmissions).

The metrics can be used for comparison with other mobility approaches, such as Mobile IP and its variations since the metrics do not include multicast-specific features. Clearly, the particular multicast type has an impact on the mobility-related metrics. Hence, the multicast-related metrics give quantitative measures for the suitability of a multicast type for mobility support. Typical metrics are:

- Costs of the multicast distribution tree (e.g. distance between source and each receiver, and probably including other metrics, such as delay),
- Signaling overhead and latencies for multicast operations, such as subscribing and un-subscribing to/from multicast channels,
- Number of states in multicast routers per multicast group.

These multicast-related metrics can be used to compare different multicast approaches with respect to their support of host mobility. However, they are dependent on the particular multicast type.

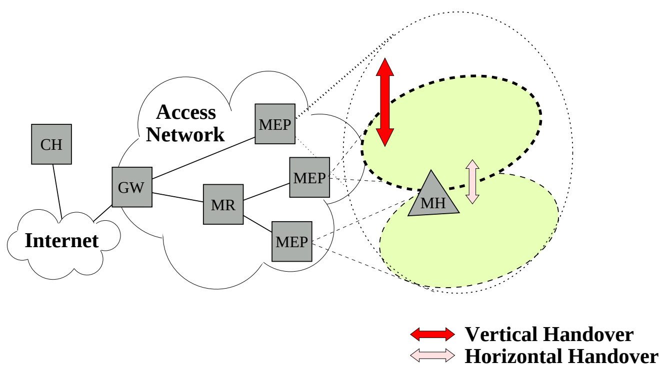

Fig. 1. Setup for performance evaluation

6 Conclusions

The *MOMBASA Software Environment* is a collection of mobility-related functionalities. Together with multicast protocols these functionalities are assembled to a software environment for multicast-based mobility support in all-IP cellular networks. The *MOMBASA Software Environment* offers already a rich set of functionalities. Nevertheless it is designed to be extended. Since IP and IP-style multicast are the subject of growing research efforts, this software environment facilitates the investigation of multicast-based mobility support using available and future multicast approaches and enhanced mobility mechanisms. Therefore the toolkit offers at least a valuable base for experimentation and measurements.

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