Wireless Bandwidth Aggregation and Load Balancing in Multi-homed NEMO

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Abstract

This paper envisages Network Mobility (NEMO) in a multi-homing context that can provide aggregated wireless bandwidth and load balancing features to multi-homed Mobile Networks. A multi-interface Mobile Router can use policy and filter information to look up the best binding per session, per flow, or per packet to get access to the Internet via multiple radio interfaces simultaneously. In NEMO, per-flow forwarding with IP tunneling has certain limitations; per-packet forwarding is a promising alternative approach. To achieve this approach, we propose a new tunneling method which is based on a modification of Stream Control Transmission Protocol (SCTP) and its extensions, referred to as *virtual SCTP tunneling*. The new tunneling method allows multiple endpoint addresses and can multiplex packets to multiple radio interfaces for a better performance in NEMO. Moreover, it reduces the tunneling overhead over radio interfaces in heavy-load situation thanks to the packet bundling feature. We carry out the simulation in the multi-homing context under ns2 and observe different metrics, e.g., throughput and packet loss rate seen by the wireless network, and the average end-to-end delay seen by Local Fixed Nodes. It is shown that the per-packet approach using *virtual SCTP tunneling* is advantageous over the per-flow approach using flow binding and IP tunneling, especially in heavy-load situation.

I. Introduction

Network Mobility (NEMO) Support [1] provides seamless mobility to Mobile Networks, which are defined as network segments or subnets that can move and attach to any points in the Internet topology; for the related terminology, see [2]. In this paper, we consider NEMO Basic Support [3][4] with mobility transparency to Local Fixed Nodes as the basic framework. Route Optimization [5] is therefore out of scope as it might be necessary to reveal the point of attachment of the Mobile Router to the Local Fixed Nodes.

The Always Best Connected (ABC) concept [6] is considered as the vision beyond vertical handover between heterogeneous access technologies. ABC has always been about multi-interface mobile nodes and multi-access networks in which the simultaneous use of access technologies is foreseen as a key feature of 4G. We envisage NEMO in a multi-homing context, of which the biggest challenge toward the ABC vision is to allow multi-interface Mobile Routers to distribute the traffic via different radio access technologies simultaneously for wireless bandwidth aggregation and load balancing features. All issues related to multi-homing in NEMO can be classified into two groups: the interaction between different entities to maintain multiple bindings simultaneously and the method of forwarding the traffic simultaneously via multiple active radio interfaces. The first group of issues can be accomplished by the Multiple Care-of Addresses extension [7]. As for the second group of issues, per-flow forwarding approach can be a potential solution for simultaneous access in NEMO and is still in the discussion of the IETF Monami6 Working Group. It is analyzed that, in NEMO, the per-flow forwarding approach using flow binding and IP tunneling requires more complexities for tunnel management at the Home Agent and Mobile Routers, limits the granularity for simultaneous access to a per-flow basis, and can not be directly applied in NEMO without using a special mechanism for differentiating flows. We propose here another approach using a new tunneling method, referred to as *virtual SCTP (vSCTP) tunneling*, which reduces the tunneling overhead on radio interfaces and allows Mobile Router traffic to be multiplexed via different radio interfaces simultaneously on a per-packet basis.

This paper is organized as follows. Section II provides a review of the framework and related work: NEMO Basic Support, Multiple Care-of Addresses extension for Mobile IP, and per-flow forwarding with IP tunneling. Section III presents a new approach for simultaneous access in NEMO with *virtual SCTP tunneling* that allows per-packet dynamic forwarding. Section IV provides performance evaluation on two approaches of per-flow forwarding and per-packet forwarding. Finally, we conclude the paper and provide perspectives for our future work.

II. Framework and Related Work

A. NEMO Basic Support

NEMO Basic Support [3] describes protocol extensions to Mobile IPv6 to enable support for network mobility. A Mobile Network is a network segment or subnet that can move and attach to any points in the Internet and can only be accessed via Mobile Routers that manage its movement. Nodes behind the Mobile Router are Local Fixed Nodes (LFNs). A Mobile Router maintains a bi-directional tunnel to a Home Agent (HA) that advertises an aggregation of Mobile Networks to the infrastructure. A Mobile Router has a unique Home Address through which it is reachable when it is registered with its Home Agent. The Home Address is configured from a prefix aggregated and advertised by its Home Agent. The prefix could be either the prefix advertised on the home link or the prefix delegated to the Mobile Router. When the Mobile Router has multiple interfaces or when there are multiple prefixes in the home link, The Mobile Router can have more than one Home Address.

When the Mobile Router moves away from the home link and attaches to a new access router, it acquires a Care-of Address from the visited link. As soon as the Mobile Router acquires a Care-of Address, it immediately sends a Binding Update to its Home Agent as described in [4]. When the Home Agent receives this Binding Update, it creates a cache entry that binds the Mobile Router's Home Address to its Care-of Address at the current point of attachment. The Mobile Router set a flag (R) in the Binding Update to indicate to the Home Agent that it acts as a Mobile Router and provides connectivity to nodes in the Mobile Network. The extension defines a new Mobility Header Option for carrying prefix information. If the Mobile Network has more than one IPv6 prefix, it can include multiple prefix information options in a single Binding Update. The Home Agent sets up forwarding for each of these prefixes to the Mobile Router's Care-of Address and acknowledges the Binding Update by sending a Binding Acknowledgement to the Mobile Router. Once the binding process finishes, a bi-directional tunnel is established between the Home Agent and the Mobile Router. The tunnel endpoint addresses are the Mobile Router's Care-of Address and the Home Agent's address. All traffic between the Local Fixed Nodes and Correspondent Nodes passes through the Home Agent and the tunnel. The Route Optimization is out of scope of NEMO Basic Support.

Even though NEMO Basic Support does not discuss multi-homing, [8] provides a full analysis on multi-homing in NEMO with different cases of multi-homing and related issues. In [9], an IPv6 soft handover extension for NEMO Basic Support (NEMO-SHO), using packet bi-casting and combining with multi-interface Mobile Routers, has been proposed and experimented.

B. Multiple Care-of Addresses Registration

The objective of the IETF Monami6 Working Group (WG) [10] is to deal with the simultaneous use of multiple addresses for either Mobile Nodes using Mobile IPv6 or Mobile Routers using NEMO Basic Support. The Monami6 WG provides a protocol extension that supports the registration of multiple active IPv6 Care-of addresses for a given Home address to allow the Mobile Node or the Mobile Router to get Internet access through multiple radio interfaces simultaneously [7]. A new identification number, called Binding Unique Identifier (BID), must be carried in each binding for the receiver to distinguish between the bindings corresponding to the same Home Address. The BID is used as a search key for a corresponding entry in the binding cache in addition to the Home Address. When a Home Agent and a Correspondent Node (CN) check the binding cache database for the Mobile Node, it searches a corresponding binding entry with the Home Address and BID of the desired binding. If necessary, a Mobile Node can use policy and filter information to look up the best binding per sessions, flow, packets. Note that a multi-interface Mobile Router can have more than one Home Address. Mobile IPv6 has mechanisms to manage multiple Home Addresses based on Home Agent's managed prefixes such as mobile prefix solicitation and mobile prefix advertisement. However those Home Addresses are seen as separated from each other. The Multiple Care-of Addresses Registration extension recommends assigning only a single Home Address to a Mobile Router with the assumption that applications will not need to be aware of the multiplicity of Home Addresses.

C. Per-flow Forwarding with IP Tunneling

Also in the Monami6 WG, the concepts of flow and flow binding are proposed: A flow is defined as one or more connections having the same flow identifier. A single connection is identified by the source and destination IP addresses, transport protocol number and the source and destination port numbers. A flow binding is a mobility binding extended with a flow identifier; it associates a particular flow to a Care-of Address without affecting other flows using the same Home Address.

An extension for flow binding [11] introduces the Flow Identifier Option, which is included in the Binding Update message and used to describe a flow to the recipient of the Binding Update. Using the Flow Identifier Option introduced in this specification, a Mobile Node or Mobile Router can bind one or more flows to a Care-of Address while maintaining the reception of other flows on another Care-of Address. If the IP tunneling method and the flow binding are used to distribute flows via multiple active radio interfaces, the decision for flow binding must be done by Mobile Routers, based on local policies within the Mobile Router and based on information about network characteristics.

Supporting mobility transparency to Local Fixed Nodes implies that the flow binding policy exchange can not apply to Local Fixed Nodes. This causes the lack of information of Local Fixed Nodes' flows that is necessary for flow binding. Besides, while Mobile Routers are moving from one wireless link to another, the dynamic nature of the network characteristic can also has negative impact on flow binding. For these reasons, per-flow forwarding may become a rigid mechanism in NEMO. As a result, the performance (e.g. throughput, end-to-end delay) for both the overall wireless network and the Mobile Network is limited. Besides, in a multi-homing context, IP tunneling supports only one address for each endpoint, the use of IP tunneling for multi-homing implies using a multitude of bi-directional tunnels and results certain complexities for the tunnel management at the Home Agent and Mobile Routers. In the next session, we present a per-packet approach using *virtual SCTP tunneling* as an alternative solution.

III. Per-packet Dynamic Forwarding with Virtual SCTP Tunneling

We have first presented in [12] a new *virtual SCTP tunneling* method, based on a modification of Stream Control Transmission Protocol (SCTP) [13][14] and its extensions [15][16] that support multi-streaming and multi-homing. The 'virtual' term signifies the fact that we apply the concepts of SCTP to tunnels having multi-homed endpoints. As a result, a virtual SCTP tunnel and a SCTP association are isomorphic, i.e. can be mapped onto each other, and we can reuse the design, and implementation of SCTP with minor modifications, principally in the encapsulating packet structure. The *virtual SCTP tunneling* is considered as a lightweight SCTP in terms of functionalities.

A. Multiple Endpoint Addresses Configuration

Unlike IP tunneling, *virtual SCTP tunneling* supports multiple addresses for each endpoint; therefore it reduces the tunnel management complexity and the system resource usage. Let m denote the number of source endpoint addresses and n denote the number of destination endpoint addresses; it is essential to have only one tunnel device for the communication between the two multi-homed endpoints with *virtual SCTP tunneling* but mn tunnel devices with IP tunneling. At the Home Agent and Mobile Routers, the destination address list of the virtual SCTP tunnel is synchronized with the Care-of Address list when the Mobile Router is moving by using predefined SCTP primitives such as *Add IP Address* and *Delete IP Address*.

B. Per-packet Dynamic Forwarding

In NEMO, the traffic between the Home Agent and a Mobile Router consists of many flows between different Correspondent Nodes and different Local Fixed Nodes. If the Mobile Router doesn't have any special agent to differentiate flows, the traffic is seen as one big flow and should be multiplexed through different radio interfaces on a per-packet basis to increase the Mobile Network performance and the whole NEMO system performance. We consider the tunnel as a virtual SCTP association between two virtual SCTP endpoints. One virtual SCTP endpoint is the Home Agent, and the other is the Mobile Router. Traffic from Correspondent Nodes to Local Fixed Node is tunneled between the Home Agent and the Mobile Router through the virtual SCTP tunnel (see Fig. 1).

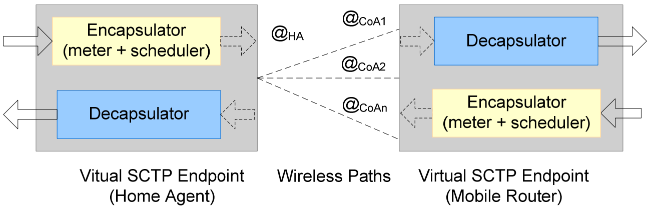
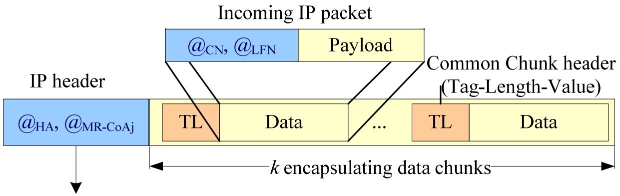


Figure 1: A bidirectional virtual SCTP tunnel

Instead of having packets distributed rigidly on a per-flow basis by the underlying routing mechanism, an intelligent scheduler is introduced inside the encapsulator to allow the cooperation of different active radio interfaces and provides dynamic and flexible per-packet forwarding. A meter estimates the arrival rate of the incoming traffic, which is later used by the scheduler for predictive packet bundling.

C. Encapsulating Packet Structure and Packet Bundling

The *virtual SCTP tunneling* method can bundle multiple small packets in one encapsulating datagram in case that multiple incoming packets are ready for processing in the tunnel's queue. This technique allows all encapsulated packets between the Home Agent and the Mobile Router to share the same IP header and therefore reduces significantly the tunneling overhead over the radio interfaces. As there is no need to de-multiplex the traffic to particular applications at tunnel endpoints, the SCTP common header is removed to optimize the encapsulating datagram structure. In case of no packet bundling, the encapsulating datagram structure will be the same as in IP tunneling (IP-in-IP or GRE). Only one bit in the IP header is required to mark the presence of packet bundling; in implementation, this can be the least significant bit (LSB) of the *FlowID* field in IPv6 or a reserved bit in IPv4. On presence of packet bundling, each incoming packet will be put in an encapsulating data chunk, of which the chunk header is the same as described in the common chunk header and has the form of Tag-Length-Value. Fig. 2 shows a simple schema for an encapsulating datagram with k encapsulating chunk; each encapsulating chunk contains an incoming IP packet.



One bit is needed to mark the presence of packet bundling
(e.g. LSB of flowid field in IPv6, or reserved bit in IPv4)

Figure 2: A simple encapsulating datagram

The activation of packet bundling is done based on the tunnel's queue length and/or in a predictive manner. When processing a packet, the scheduler attempts to bundle it with other in-queue packets and forward the encapsulating packet as soon as possible. If the queue is empty, the scheduler predicts a potential packet bundling by using meter's information and wireless path characteristics. If potential packet bundling is not allowed, the packet is encapsulated and forwarded immediately; otherwise, the scheduler injects some small waiting delay to the packet without increasing its end-to-end delay. Upon next arrival or time out, the incoming packet is encapsulated and forwarded respectively with or without packet bundling. This predictive algorithm requires further research and its details are out of scope of this paper.

IV. Performance Evaluation

D. Simulation Description

We carry out the simulation under network simulator 2.29 with NO Ad-Hoc (NOAH) routing extension and with our extensions for multi-interface Mobile Routers, *virtual SCTP tunneling* and manual routing in the hierarchical addressing mode. The scheduler inside the tunnel's encapsulator distributes the traffic to different Care-of Addresses, i.e. to different radio links, on a per-packet basis, and in a simple manner using the Round-robin algorithm.

The IPv6 simulation topology, see Fig. 3, includes one Home Agent and two Access Routers (ARs). Both Access Routers have IEEE 802.11 as the access technology and the capacity of 5.5Mb/s. Different values of delay are used for different Home Agent-Access Router links as the first step to simulate the difference in wireless path characteristics. Different error transmission characteristics will be considered in our future work. It is assumed that each Mobile Network has only one Mobile Router which has two egress interfaces; each interface associates to one Access Router via the wireless link.

All Mobile Routers are in the coverage of both Access Routers and uniformly positioned in this region. This simulates fully-overlapped coverage of different radio access technologies and allows Mobile Routers to have simultaneous access to the routing infrastructure, i.e. to the Internet. We consider 5 different Mobile Networks; the number of Local Fixed Nodes inside each Mobile Network is 15, 10, 10, 5, and 5 respectively.

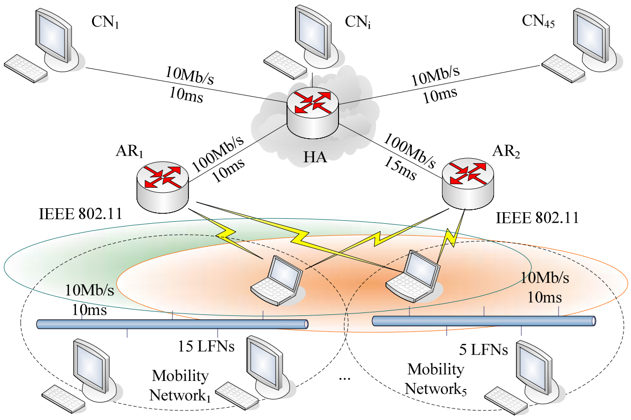


Figure 3: Simulation topology

We use two traffic classes to survey service differentiation: the first traffic class using G.728 as Pulse Code Modulation codec consists of 20 VoIP flows, each flow creates VoIP packets of 100 bytes (52-bytes UDP payload) at a 20-ms sample interval; the second traffic class consists of 25 video or data flows, each flow creates packets of 1024 bytes at a 20-ms interval. A random bijection between the set of Correspondent Nodes and the set of Local Fixed Nodes is initialized. A flow is initialized for each pair CN-LFN and is randomly bound to a radio interfaces as follows: for each run, generate a random number r in the range of 0.2 and 0.8 uniformly; for each flow, generate a random number x in the rage of 0 and 1; if $x < r$, bind the flow to the first interface, otherwise, bind the flow to the second interface. 20 flows of the first traffic class are gradually initialized at random starting time. Later, 25 remaining flows of the second traffic class are initialized in the same manner. The observation is carried out, with 100 simulation runs, on the following metrics: system offered load, traffic class throughput and average end-to-end delay. For each metric, we also estimate and plot the 95% confidence interval of sample means.

E. Performance Results and Analysis

Fig. 4 shows results for the first traffic class, and Fig. 5 shows results for the second traffic class. Fig. 4a and 5a represent the impact of system offered load on each traffic class throughput while Fig. 4b, 4c, 5b and 5c represent the impact of number of active Local Fixed Nodes on the packet loss rate and the average end-to-end delay for each traffic class. In all cases, the *virtual SCTP tunneling* with packets bundling feature (i.e. the number of encapsulating chunk k is greater than one) provides the highest throughput and the lowest loss rate. For example, see Fig. 4b, if the maximum tolerated packet loss rate for a VoIP connection is 5%, the maximum number of supported active Local Fixed Nodes when using IPv6 tunneling, *virtual SCTP tunneling* without and with bundling is respectively 24 (the worst), 28 (better) and 29 (the best). In heavy-load condition, the *virtual SCTP tunneling* provides smaller average end-to-end delay and better throughput for both traffic classes thanks to the load balancing feature. In overload condition, it provides higher throughput and smaller packet loss rate with larger delay as a trade-off. However this trade-off is worth for applications, e.g. data transfer or video streaming, where lost packets cause negative impact on the QoS. Besides, our observation also shows that service differentiation in multi-homed NEMO is still an open challenge that requires more research efforts.

Conclusions

This paper proposes a novel *virtual SCTP tunneling* for wireless bandwidth aggregation and load balancing support in multi-homed NEMO. The new tunneling method reduces the tunneling overhead on radio interfaces and can multiplex incoming traffic simultaneously via different active radio interfaces on a per-packet basis. Our approach is advantageous over the per-flow approach using IP tunneling in terms of throughput, packet loss rate, as well as end-to-end delay. In the future, we will optimize the scheduling algorithm in consideration of mobility, service differentiation and feedback information from Access Routers about the wireless link characteristics and wireless link capacity.

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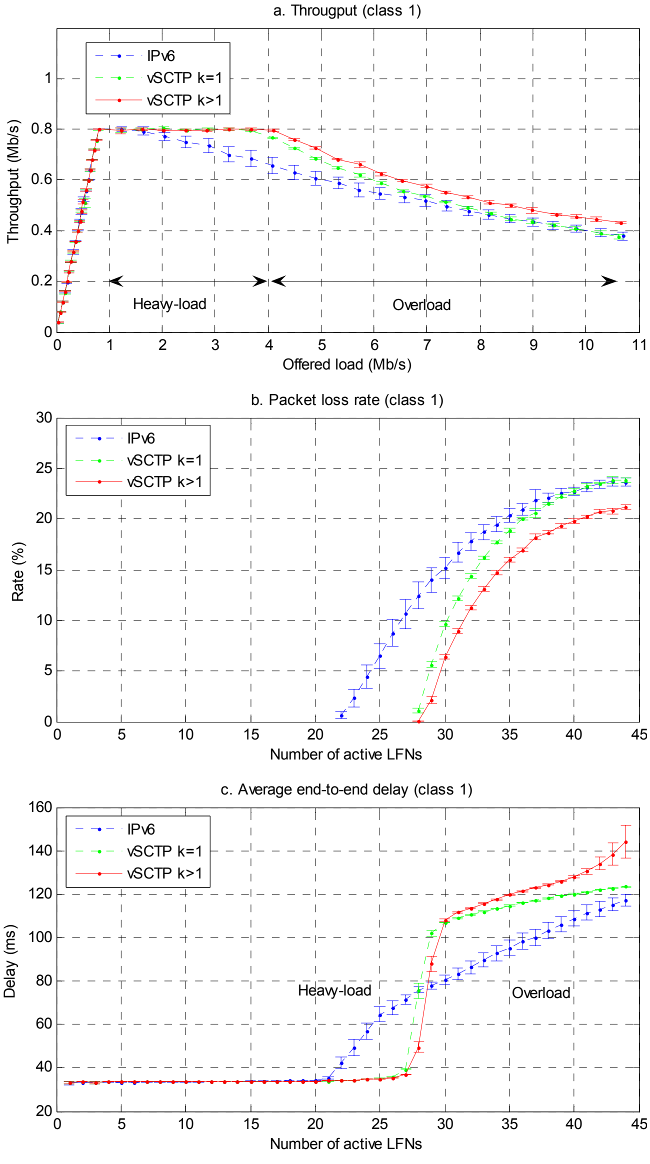

Figure 4: Simulation results for the first traffic class

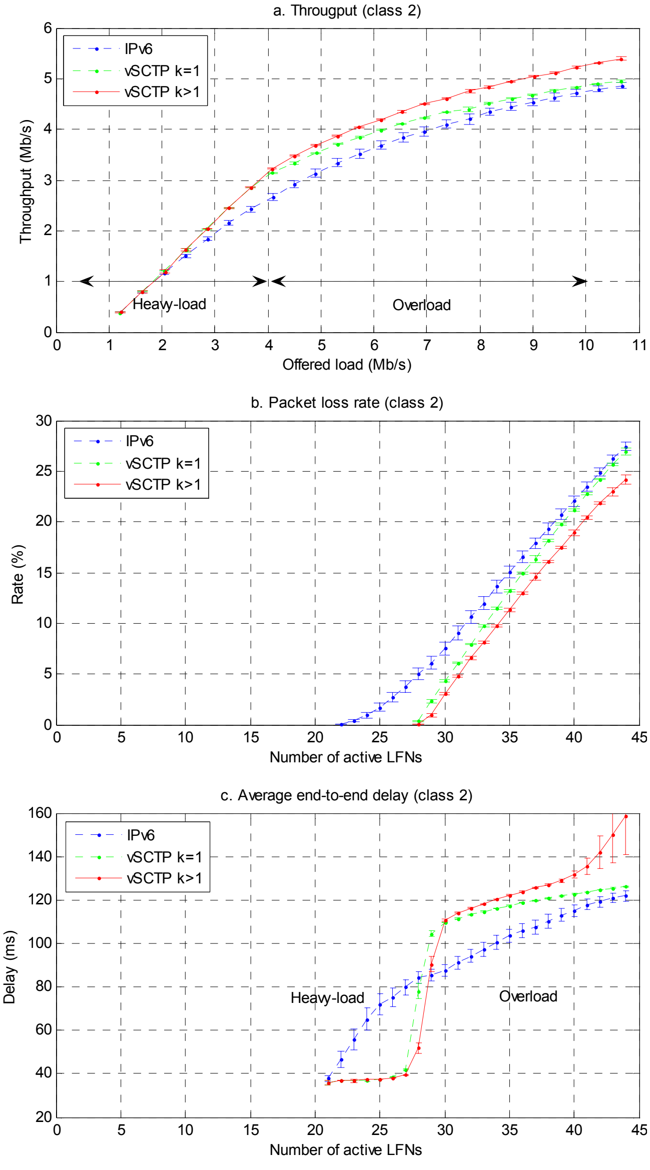

Figure 5: Simulation results for the second traffic class