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Smooth Adaptive Soft Handover Algorithm for Multimedia Streaming over Wireless Networks

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***Abstract*—Inter-network mobility is achieved by allowing a mobile node to change its point of attachment to the network while preserving connectivity to its corresponding nodes.**

Most handover solutions proposed in the literature directly change the whole data flow from one network to another relying on only one network to transfer the entire data stream. These solutions involve a certain amount of quality degradation due to increasing loss and delay and suffer in terms of scalability, efficient resource allocation and resilience to different mobile node speeds. This paper proposes the Smooth Adaptive Soft-Handover Algorithm (SASHA) which increases the quality of the multimedia delivery process when performing handover in heterogeneous wireless environment by gracefully transferring the load from one connection to the other.

Keywords-heterogeneous mobile networks, handover, load balance, multimedia streaming.

I. INTRODUCTION

Mobile networking has encountered a rapid growth with the latest advancements in wireless technologies and increase in the number of mobile computing devices. At the same time multimedia applications like IPTV, video-on-demand, distance learning and teleconferencing are some examples of multimedia applications that are attracting increasing interest among mobile device users.

As the Internet was originally designed for communication between fixed devices [1], mobility management should be additionally provided to accommodate mobile devices. Multimedia streaming to mobile users over wireless networks involves difficult challenges in terms of mobility support due to the high sensitivity of multimedia quality to network conditions.

Different solutions such as Mobile IP, Mobile SCTP, Mobile DCCP, etc. were developed to support handover at different layers [1]. Most of these proposed solutions directly change the whole data flow from one network to another as the mobile nodes roams through different networks coverage area.

However their main drawback is the lack of a quality-oriented approach, which would combine handover, network selection and load balancing techniques in order to maximize user perceived quality by efficiently exploiting all the communication resources currently available.

This paper proposes the Smooth Adaptive Soft Handover Algorithm (SASHA), as an application-layer quality-aware approach to handover, based on load balancing among different networks. This proposed handover algorithm exploits both the old and the new connections to transfer multimedia data when the user is crossing the two networks overlapping area. In this context SASHA transfers gracefully multimedia streaming process from the old fading connection to the new improving one. This operation is performed efficiently without data duplication.

SASHA is compared with two other solutions which perform the handover at different layers (i.e., transport and network) based on switching the data traffic from one network to the other using a make-before-break and break-before-make approach respectively.

The structure of the paper is as follows. Section II presents and compares some existing handover management schemes. In section III the proposed adaptive handover algorithm is presented. Section IV details the simulation environment, presents testing results and performs result analysis. At the end conclusions and possibilities for further work are described.

II. RELATED WORK

This paper focuses on handover management in the context of multimedia streaming. Handover management allows the mobile node to change its point of attachment to the network without losing connectivity with its corresponding nodes. There are several solutions for handover management proposed at different layers of the network protocol stack. The following sub-sections briefly describe some of these solutions.

A. Network Layer Handover

Mobile IPv4 (MIPv4) and Mobile IPv6 (MIPv6) [2] are the main solutions to provide mobility at the network layer.

Basically mobility using MIP is achieved by tunneling the data flow from the Home Agent (HA) to a Foreign Agent (FA). The HA resides within the home network of the Mobile Node (MN) and the FA represents the foreign network visited by the MN. The MN will send binding updates to HA to inform it about its current location. MIP presents high handover latency, packet loss and poor scalability.

Several handover enhancements for IPv6 were developed

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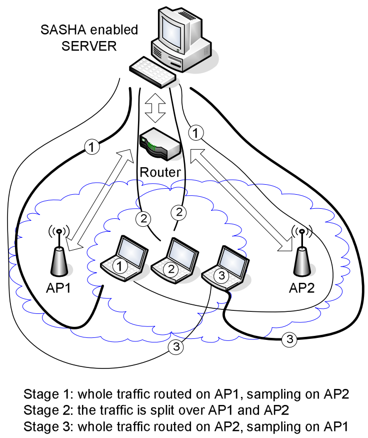

Figure 1. Handover operation using SASHA

[3] like routing optimization, hierarchical and anticipation techniques.

Hierarchical Mobile IPv6 (HMIPv6) [3, 5] uses a network organization based on domains, which contain several access routers (AR) and a Mobility Anchor Point (MAP), that connects the domain to the Internet. This solution improves handover latency for handover within the domain (micro-level), but macro-level handover still presents performance issues.

Fast Handover Protocol (FMIPv6) [2, 4] uses Link layer events (triggers) to improve the handover performance in terms of packet loss by anticipating the handover and tunneling the packets to the new AR. This solution provides a substantial improvement of handover latency and packet loss, but does not provide a seamless transition between the old and the new AR. The drawback is the precise coordination required between the MN, and ARs and the unpredictability of packets arriving at the AR.

FMIPv6 outperforms HMIPv6 in terms of handover latency and packet loss [6], but a solution combining both approaches would give better performance than each of them separately.

B. Transport Layer Handover

Several mobility enhancements were proposed in [7, 8, 9] for TCP and UDP, which are the main protocols used at transport layer in the Internet.

The mobile SCTP (mSCTP) [10] extends the newly developed Stream Control Transmission Protocol (SCTP) to support mobility. mSCTP allows each of the endpoints of an association to add a new IP address and delete an unnecessary one and to set the primary IP address without interrupting data transfer. However the conditions in which the primary address is changed and how this relates to quality of service remain an open issue.

A mobility support solution for Datagram Congestion Control Protocol (DCCP) is presented in [11], which uses a generalized connection that includes several normal DCCP connections. During the handover a new connection is added using the new IP address while the old connection is deleted.

This solution could provide seamless handover, but no efficient algorithm for managing the traffic over the group of normal connections is specified.

C. Application Layer Handover

Mobility support at application layer has also been attempted and two solutions are discussed here: one using Session Initiation Protocol (SIP) [12] and the other using MOBIKE [13].

The basic idea of handover using SIP involves the MN sending a RE-INVITE message to the Corresponding Node (CN) when it gets a new IP address. This message informs the CN about MN's new address. Handover using SIP can involve latency for signaling and overhead for IP encapsulation [1]. Some enhancements to SIP mobility were also proposed. A solution for reducing handover latency by proactively processing the new address allocation and session update is presented in [14].

MOBIKE was developed as an extension to Internet Key Exchange version 2 (IKEv2) [15]. MOBIKE allows both MN and CN to have several IP addresses that could be used. When the MN changes its IP address it sends a notification to the CN about the new address. MOBIKE permits the MN to move, but does not specify how the decision is made to change the IP addresses used for data exchange.

III. Smooth Adaptive Soft Handover Algorithm For Multimedia Streaming To Mobile Users Over Wireless Networks

In the context of heterogeneous wireless networks any mobile device has access to several networks using different wireless technologies. Due to the movement of the mobile device, the variability of network characteristics and loads these paths will encounter a certain level of dynamicity in terms of availability, QoS, cost, stability, etc.

This section presents a novel handover management solution which considers these differences and enables quality-awareness during multimedia streaming to mobile devices in heterogeneous wireless network environments.

A. Novel Handover Management Scheme

Smooth Adaptive Soft-Handover Algorithm (SASHA) is a handover management solution which increases the quality of the multimedia delivery process when performing handover in heterogeneous wireless environment by gracefully transferring the load from one connection to another. The capacity of a connection to transport a specific data stream is evaluated using the Quality of Multimedia Streaming (QMS) metric which will be described in the next section. The content is distributed (redistributed) continuously over the available communication channels based on the QMS values.

Figure 1 presents schematically a horizontal handover performed using SASHA involving two networks using infrastructure modes and having AP1 and AP2 as access points (access routers). The assumption that the mobile node is

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Input: Relevant data to compute QMS for each path such as number of received packets, lost packets, etc.
Output: R1, R2 – sending rate for path 1and 2

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Procedure: Update_Rate
      Compute QMS1;
      Compute QMS2;
      if  QMS1 > QMS2 + Step then
          increment R1;
          decrement R2;
        else
          decrement R1;
          increment R2;
```

Figure 2. SASHA Rate Adaptation Algorithm

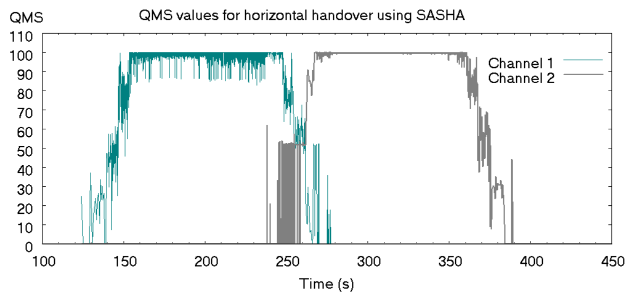

Figure 4. QMS values sample for handover using SASHA.

equipped with two network interfaces is made. The example refers to horizontal handover but the same technique can be used for vertical handover considering an all-IP network environment. Although the handover process is continuous, for simplicity three different stages will be identified and presented.

In stage 1 the MN is currently communicating entirely over AP1 and enters the overlapping area. When the link via AP2 becomes available, MN opens a new connection to the server which sends a low bitrate sampling stream over the new AP2 path for QMS computation. As QMS metric is evaluated for the two connections and mainly due to the high distance to AP2, QMS2 is very much lower than QMS1.

In stage 2 MN moves towards AP2 determining QMS decrease for the AP1 path and QMS increase for the AP2 connection. As QMS values change, SASHA server starts gradually to increase the share of multimedia content delivered over the new AP2 connection and decrease the load of the AP1 connection.

In stage 3 MN is about to leave the overlapping area and enter exclusively in the AP2 coverage area. In this situation, as QMS value for the AP1 link decreases significantly, whereas the QMS value for the AP2 connection becomes very high, all multimedia traffic will be routed over AP2 connection. However AP1 connection is still sampled while still available in order to compute QMS values, allowing the handover process to be reversed, if MN moves back towards AP1.

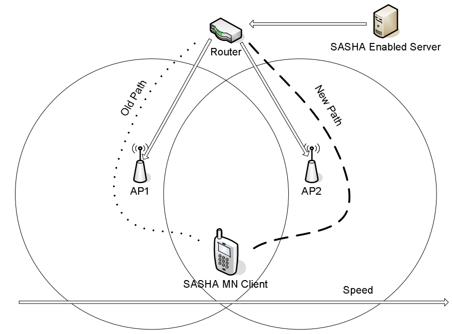

Figure 3. Simulation scenario involving two WLANs with access points (access routers) AP1 and AP2 and a mobile node MN

B. Quality of Multimedia Streaming Metric

Multimedia content deliveries over various communication links which differ in terms of technology, load, cost and even protocol influence differently multimedia quality. Therefore the Quality of Multimedia Streaming metric is used to describe and quantify the effect all these factors have on the multimedia delivery quality.

QMS is represented by the function from equation (1) and is dependent on the characteristics of the connection *i*.

$$QMS^i = w_1 * QoS^i_{grade} + w_2 * QoE^i_{grade} + w_3 * NCost^i_{grade} + w_4 * PEff^i_{grade} + w_5 * UPref^i_{grade} \quad (1)$$

QoS^i_{grade} represents the grade which assesses the network QoS for the connection *i* and is computed based on individual values of bandwidth, packet loss, delay and jitter [16]. QoE^i_{grade} estimates user Quality of Experience (QoE) and is computed using objective quality metrics (i.e., Peak Signal-to-Noise Ratio (PSNR)) for the video stream transported by connection *i*. Calculating PSNR on the decoded image is a time consuming operation which may affect the delay-sensitive real-time streaming process. To overcome this drawback PSNR is estimated with relative good accuracy based on throughput and loss rate which decreases the feedback delay. $NCost^i_{grade}$ is a cost related component and is computed based on the user cost-utility rating of the provided service [17]. $PEff^i_{grade}$ represents the energy efficiency score of connection *i* with respect to the MN power usage. $UPref^i_{grade}$ is computed based on user preferences for a certain network interface (technology).

All these component grades are normalized and have values in the [0, 100] interval. In order to allow for flexibility, different weights were associated with each component. These weights are set based on either user preferences or application requirements. Weight normalization is required, so the condition from equation (2) needs to be respected.

$$\sum_{1}^{5} w_i = 1 \quad (2)$$

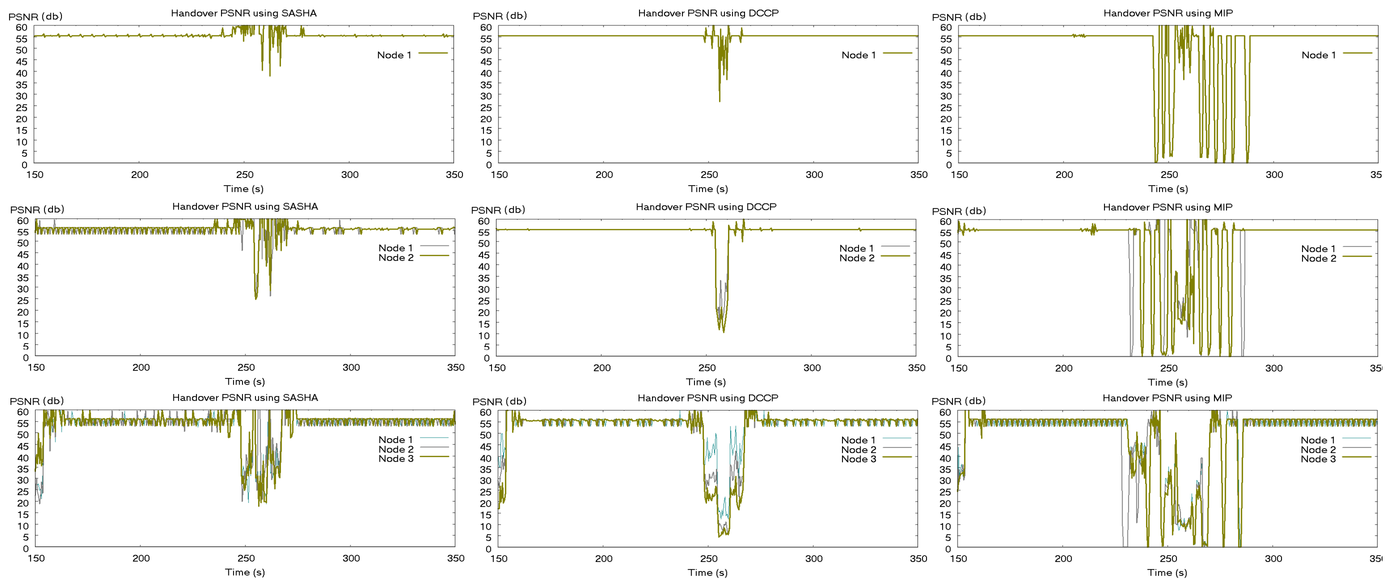

Figure 5. Handover Loss using SASHA, MIP and Mobile DCCP

C. Quality Monitoring and Decision Making

Figure 2 presents an illustration of the pseudocode of SASHA rate adaptation when the handover is performed between two separate paths. Rate update (Update_Rate) is performed each time there are updates of the QMS parameters values such as when a new quality or performance report is received from the client, new information is harvested from the lower network layers, etc. The client-side SASHA module measures the network QoS parameters (i.e., throughput, loss, delay, jitter) and also estimates PSNR and periodically sends these values as feedback to the server-side module. IEEE 802.21 standard may also be considered for harvesting network state information. Based on this feedback the server-side SASHA module computes the QMS score for each channel separately.

If the difference in QMS is significant according to the required algorithm sensitivity (a step value was introduced), the rate adaptation is performed by increasing the streaming rate over the connection with higher QMS and by decreasing the rate on the other connection.

The sensitivity and reaction speed of the algorithm has to be correlated with the dynamics of the networks in terms of load fluctuations and also with geographical aspects such as size of the overlapping area of the two APs and also MN speed and trajectory. These aspects of algorithm tuning are beyond the scope of this paper.

IV. Simulation-based Testing, Results and Analysis

A. Simulation Environment

Performance evaluation of the proposed solution was conducted using the NS-2 Network Simulator (v2.29) [18]. The realistic radio patch developed by Marco Fiore [19] was used to achieve results as close as possible to a real life scenario. The simulation scenario consists of two wireless access points (access routers) which are connected to a router which is further connected to the broadcasting server as presented in Figure 3. Hierarchical routing was used, and the two access points (access routers) were provided with addresses from different domains. To simulate the distinct connections over the two networks the mobile node was created by attaching two wireless nodes, each being assigned with an address from one of the specified network domains.

The two access points (access routers) were positioned close enough to each other (~ 170 m) to provide a sufficient overlapping coverage area. To evaluate the scalability of the tested handover schemes with the number of MNs, one, two and three nodes were considered to perform handover simultaneously.

Table 1 Results for SASHA, Mobile DCCP and Mobile IP when streaming a maximum of 1.5Mbps video

	Nodes No.	**PSNR**		**Throughput**		**Loss**	
		Average (dB)	***%***	***Average (Mbps)***	***%***	***Average (Mbps)***	***%***
SASHA	1	60.9	-	1.50	100	0.018	1.20
	2	55.2	-	1.50	100	0.027	1.80
	3	44.9	-	1.36	90	0.179	11.9
Mobile DCCP	1	54.0	-	1.49	99	0.000	0.00
	2	47.2	-	1.38	92	0.008	0.56
	3	32.9	-	1.16	77	0.291	19.5
Mobile IP	1	42.1	-	1.20	80	0.305	20.3
	2	35.0	-	1.00	66	0.491	32.7
	3	18.7	-	0.82	55	0.668	44.6

B. Handover Models

For evaluation purposes several simulation handover models were used. For MIP the standard implementation distributed with NS-2 was used. An optimistic simulation model of Mobile DCCP was developed under NS-2. Each MN was enhanced in order to be capable of alternative communication with two APs. To simulate a perfect handover, the multimedia data was sent via AP1 and then - at the appropriate moment - via AP2. The delays involved by switching the data flow from one AP to the other were not considered.

To implement SASHA, changes were made to the wireless nodes to allow multi-channel communication. Each node has several interfaces for wireless communication and the active channel can be set for each node separately in the mobile routing agent. SASHA was deployed in an application that is capable of sending a constant bitrate multimedia content. For connection assessment, the cost of the connections is considered to be the same, the power efficiency is similar for both interfaces and as the same technology is used for both connections, there is no difference in user preference for one or the other connection. QoS component uses average loss, delay and jitter, whereas the QoE component uses PSNR to assess user perceived quality. The weights were considered to be equal for all the QMS components with the condition from equation (2) being respected. Figure 4 presents sample QMS variation for handover performed using SASHA.

C. Simulation Scenario

Three mobility solutions were used for performance evaluation: SASHA, Mobile IP (MIPv4) [20] and Mobile DCCP [11].

A MN is crossing the two APs coverage areas at a speed of about 5 km/h performing handover according to one of the three solutions when passing through the networks' overlapping area. Three different node mobility scenarios are considered when a single, two and three nodes respectively cross the overlapping area at the same time. The multimedia server is streaming multimedia at a constant rate of 1.5Mbps.

The goal of the simulations is to determine the capability of each handover technique to maintain high level of user perceived multimedia quality. Consequently in this paper no multimedia adaptation techniques were employed.

D. Performance Evaluation

Figure 5 compares the performance of the three solutions in terms of end-user perceived quality as estimated by PSNR. Average value of PSNR is 55dB and is achieved with small fluctuations outside the handover period by all the solutions evaluated. Mobile DCCP performs well for one node, but encounters low PSNR for two and three nodes. In case of three nodes performing handover simultaneously Mobile DCCP achieves a PSNR score as low as 5dB for a period of 6 seconds. During handover Mobile IP presents drops in PSNR as low as 0dB for periods of time around 2 and 3 seconds and for three nodes performing handover simultaneously also presents a drop of PSNR at the value of 10dB for almost 7 seconds. As seen in Figure 5 SASHA scales better and PSNR demonstrates it. In the worst case scenario, when three MNs do the handover using SASHA, PSNR drops to 25dB for around 5 seconds, performing much better than the other two solutions.

E. Results Analysis

Table 1 presents the average results in terms of loss, PSNR and throughput for the three mobility solutions evaluated and different number of MNs performing simultaneous handover.

It can be observed for each of these solutions the impact of the number of nodes on the multimedia streaming performance and user perceived quality. For example Mobile DCCP presents no loss for the one MN case, 0.56% loss for two nodes case and 19.5% loss for three MNs.

A similar trend can be observed for Mobile IP, 20.3% loss for one MN and 44.6% loss for three nodes. SASHA scales better with a 0.01% loss for one node, 1.8% loss for two nodes, and 11.9% loss for three MNs. The same scalability can be observed for throughput and PSNR, with a 90% of the maximum multimedia bitrate as throughput for SASHA in the three MNs case, 77% for Mobile DCCP and 55% for MIP in the same conditions.

V. Conclusions and Future Work

As mobility represents a crucial component for the future Internet where mobile wireless-enabled devices are widely used, this paper presents a quality-oriented mobility solution for multimedia applications. The solution relies on efficient utilization of all the communication resources available by gracefully and dynamically distributing the load over them based on their estimated contribution to maximizing the end-user perceived quality when streaming multimedia content.

This paper proposed a novel Smooth Adaptive Soft Handover Algorithm (SASHA) which gracefully performs handover at application level between candidate networks. Simulation-based tests show that SASHA offers a 35% improvement compared to Mobile IP and 13% compared to Mobile DCCP in terms of throughput. Consequently much higher end-user quality is achieved in comparison with both solutions.

Future work will assess the performance of SASHA for different mobility scenarios, with different node speeds, variable wireless coverage overlapping areas and with even higher number of mobile nodes. The effect of the QMS components on the handover performance in various network conditions will also be assessed in order to determine the optimal weights allocation. The possibility of dynamic weights allocation during handover will also be considered. Streaming variable bitrate multimedia and using adaptive streaming techniques will be considered as well as the effect of background traffic on the performance of SASHA.

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