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mSIGMA: an Efficient Handoff Scheme for Multi-Class Networks

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***Abstract*— Wireless networks are becoming more heterogeneous; different classes of networks co-exist and users want to connect to any available network, anytime. So, it is important to have a mobility management scheme that can manage handoff for both inter-class and intra-class mobility so that the users can connect to and roam between any network. We propose an end-to-end mobility management scheme, Multi-class SIGMA (mSIGMA), that performs soft handoff for inter-class and intra-class mobility in wireless network. Our analysis shows mSIGMA performs seamless handoff across networks with low delay and packet loss. We have also shown though experimental analysis that mSIGMA is implementable with existing networking technologies and can perform handoff efficiently.**

Keywords: Multi-class network, vertical handoff, mobility management

I. Introduction

When a mobile host (MH) changes its point of attachment, its IP address gets changed. An MH should be able to maintain all the existing connections using the new IP address. This process of changing a connection from one IP address to another one in IP network is called handoff. As the amount of real-time traffic over wireless networks keeps growing, the deficiencies of the network layer based Mobile IP, in terms of latency and packet loss becomes more obvious. Since most of the applications in the Internet are end-to-end, a higher layer mobility solution is required, and handoff is now being implemented at different layers of the protocol stack. When this handoff occurs across networks in an overlay network, it is called vertical handoff.

Today's network is becoming more and more a combination of diverse wireless networks to provide wider coverage and higher bandwidth to the users. When a network is combination of multiple subnetworks and their coverage areas are overlapping, this heterogeneous property of network is giving wireless multi-class network. A *multi-class network* is formed when the subnets are consists of different network technologies, such as WLAN and GPRS. In such a network, an MH can travel between same class network, such as from one WLAN subnet to another WLAN subnet, or across a subnet, such as from one WLAN subnet to a GPRS subnet. A mobility management scheme needs to have the ability to perform both regular handoff and vertical handoff to operate in a multi-class network.

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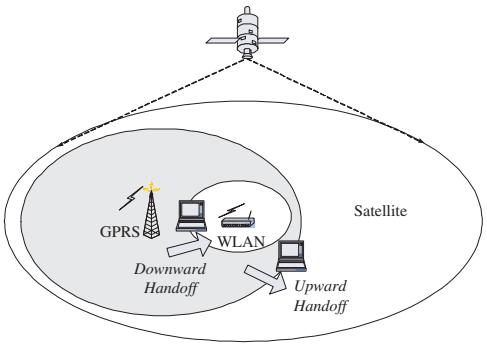


Fig. 1. Handoff in a multi-class networks.

There are two types of vertical handoff: i) upward handoff: when a MH moves from a Lower Coverage Network (LCN), such as WLAN, to a Higher Coverage Network (HCN), such as GPRS, which usually has lower bandwidth than an LCN; and ii) downward handoff: when MH moves from HCN to a LCN. Fig. 1 illustrates the vertical handoff types.

There are several works in the literature on vertical handoff. Proactive vertical handoff takes place when handoff decision is based on the presence or absence of a LCN (network with highest bandwidth and lower coverage). The MH always tries to perform a downward handoff. This class consists of BARWAN [1], mSCTP [2] and OmniCon [3]. On the other hand, when handoff is decided based on a set of decision parameters, it is active vertical handoff. Usually, the comparative signal strength is the primary handoff decision parameters. Examples of this class of handoff includes USHA [4], ABC [5], SIP [6], P-Handoff [7], BTS Based [8], MIPL [9], Gateway Based [10] and Policy Enabled [11] vertical handoff schemes. A number of these vertical handoff schemes, e.g., MIPL, OmniCon, Gateway Based and Policy Enabled, are based on the mobility solution from IETF, Mobile IP (MIP) [12]. A survey and classifications of these schemes are presented in [13]. Only a few of these schemes are tested for feasibility in *real life* with experimental testbed. These schemes focuses on vertical handoff; they don't present a generalized handoff scheme that can perform both inter-class and intra-class handoff. As MIP

is a generalized mobility architecture, the schemes based on MIP can be extended to support both types of handoffs. But MIP performs hard handoff [14] and has high handoff latency and losses.

Hence, we propose a generalized mobility scheme, Multi-class SIGMA (mSIGMA) that can perform both intra-class and inter-class handoff based on a generalized mobility architecture, SIGMA [15]. SIGMA is a mobility management scheme that performs efficient soft handoff [14] using multiple interfaces and has an effective location management scheme [16]. In a multi-class network, availability of different sized networks gives a mobile device with multiple interfaces the option to access both the networks depending on the need and the available bandwidth. We propose mSIGMA to operate in a multi-class network [13] to perform efficient handoff. The *difference* from previous works is mSIGMA is a generalized end-to-end mobility management scheme that performs soft handoff for both inter-class and intra-class handoff in a multi-class network, not just a vertical handoff scheme. We show the performance of mSIGMA using experimental setup to test its feasibility in a real life network. We also compare the performance of mSIGMA with MIP through analytical model, as MIP is underlying architecture for several vertical handoff schemes that can be extended perform both types of handoffs and is tested in real life network. In this work, we emphasize on performance analysis of inter-class handoff of mSIGMA as [15] demonstrated the intra-class handoff performance analysis and comparison for mSIGMA and MIP.

The *objective* of this paper is to design and analyze a handoff scheme, mSIGMA and to present a comparative performance analysis of mSIGMA in a multi-class network. Our *contributions* in this paper are: i) design and development of mSIGMA, ii) developing analytical model of to evaluate the performance of mSIGMA and compare it with MIP, and iii) illustrating the performance of mSIGMA with analytical and experimental evaluations.

The rest of this paper is structured as follows: Sec. II presents the fundamentals of mSIGMA. An analytical model for handoff schemes to evaluate their performance is presented in Sec. III. Sec. IV presents the performance evaluation of mSIGMA using analytical and experimental evaluations. Finally, we have our concluding remarks in Sec. V.

II. Multi-class SIGMA (mSIGMA)

mSIGMA is a generalized handoff management that can perform handoff for both inter-class and intra-class mobility. It operates based on a set of parameters to decide on its handoff. First, it decides the type of handoff it needs to perform, and then matches the appropriate parameters to make the handoff decision.

A. Parameters for mSIGMA

We identify a set of parameters that can be used to make handoff decision, for inter-class and inter-class mobility. Inter-class or regular handoff in mSIGMA is implemented for WLANs. When an MH moves from one WLAN subnet to another one, mSIGMA performs the regular handoff. On the other hand, intra-class handoff, or vertical handoff for mSIGMA is implemented for WLAN which is a low coverage but high speed network and CDMA, a high coverage network, which can be considered as ubiquitous connection. Thus, it can be assumed at any point if an MH cannot connect to a WLAN, it is still connected to a CDMA subnet. The parameter matrix in the Table is used to determine mSIGMA decision for regular and vertical handoff. Table I shows the decision parameters for mSIGMA to performs both kinds of handoffs.

mSIGMA exploits IP diversity [14] offered by multiple interfaces in mobile devices. During the handoff process, the MH has two IP addresses one for each of the subnets and communicates with both the subnets at the same time with multiple interface cards which is becoming common for mobile devices. This support for multiple IP address is called IP diversity. All the interface cards currently available in the market to connect to a CDMA network (or a GPRS) supports WLAN as well. So, for an intra-class handoff, an interface card can be configured to operate as a WLAN card and for an inter-class handoff, the same interface card can be configured to operate with CDMA. This is more elaborated in Sec. II-C.

B. Intra-class Handoff for mSIGMA

When a MH moves into the coverage of a new subnet, it obtains a new IP address while retaining the old one in the overlapping area of the two subnets. The MH communicates through the old IP address while setting up a new connection through the newly acquired IP address. Usually, the gateway for a subnet is co-located with the Access Point (AP). A gateway measures the signal strength of their APs. When the signal strength of the old AP drops below a certain threshold, the connection is handed over to the new subnet and the new IP address is set to be the primary one (step 3 in Fig. 2; colored figures are shown in [17]). When the MH leaves the overlapping area, it releases the old IP address and only communicates over the new IP address. The duration of the MH in the overlapping area and the time during which the MH communicates over both IP addresses depend on the velocity of the MH and the power of the signals from the access points. Each time the MH handoff to a new subnet, it updates the DNS with its new IP address [16].

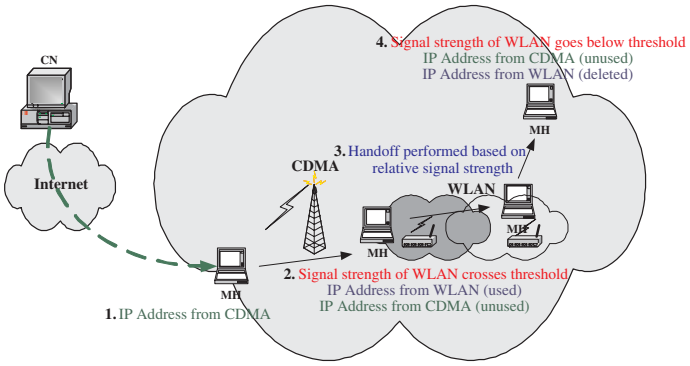


Fig. 2. Handoff topology for mSIGMA.

TABLE I
HANDOFF PARAMETERS FOR mSIGMA.

Parameter	Condition	Reason	Used for
Relative Signal Strength	use the strongest and steadier one	to have lower SNR and to avoid ping-pong effect	regular handoff
Bandwidth and QoS	use WLAN if available	CDMA low bandwidth, thus insufficient	vertical handoff
Cost	use WLAN if available	whenever data goes through the CDMA network, we get billed, WLAN is free	vertical handoff
MH Priority	always connect to CDMA, use WLAN if available	CDMA is ubiquitous, WLAN has limited coverage	vertical handoff
Absolute Signal Strength	signal strength of a WLAN subnet is above threshold	WLAN signal strength should be strong enough to receive packets	vertical handoff

C. Inter-class Handoff for mSIGMA

Inter-class handoff is also called vertical handoff. Fig. 2 illustrates the vertical handoff topology of mSIGMA. As mentioned in Sec. II-A, CDMA connection is approximated to be ubiquitous. So, it is assumed that the CDMA coverage is always available. The coverage of the WLAN thus falls within the coverage of CDMA; whenever MH moves out of WLAN, it goes into CDMA. The MH can initiate the communication either in WLAN or in CDMA (step 1 in Fig. 2). As WLAN is higher in bandwidth than CDMA, we know that the MH always tries to connect to WLAN. MH connects to CDMA through upward handoff, only when it moves out of WLAN (step 4 in Fig. 2). In the same way, whenever MH moves into WLAN, it changes its point of attachment from CDMA to WLAN through downward handoff (step 2 in Fig. 2). The vertical handoff principle is based on the fact that CDMA is always available. So, only the signal strength of WLAN is measured for handoff decision. Whenever a signal is obtained from WLAN, an IP address is obtained. When it goes up the threshold level, connection is handed over to the WLAN from CDMA. Same principle is applied for other way. Whenever the signal strength goes below the threshold, the connection is handed over to CDMA. It is possible because the IP address from CDMA is always going to be there and all it requires is to set that address as the primary one.

Algorithm for mSIGMA is shown in [17].

III. ANALYTICAL MODEL

Performance analysis of a handoff scheme depends on the time it takes to perform a handoff and packets lost during that period. In this section, we present a model to capture these two aspects of handoff to evaluate the performance of mSIGMA and MIP to evaluate their performance. Intra-class handoff performance analysis and comparison for mSIGMA and MIP can be found in [15]. In this work, we focus on the performance analysis of inter-class performance analysis of mSIGMA and its comparative evaluation with MIP. Here, we show our analysis using WLAN and CDMA network, as mSIGMA is implemented in these two networks (Sec. II-B). But the same concepts can be extended to other technologies to model other handoff schemes.

A. Analytical Model for Handoff Time

The time taken for an MH to a handoff and to change from subnet 1 to subnet 2 is called the handoff time. It can be calculated by the time difference between last packet transferred through subnet 1 and first packet transferred through subnet 2.

1) Handoff Time of mSIGMA*:* Let, τ be the time taken for a packet to travel from an MH to the CN. Usually, this travelling route takes one wireless hop at subnet 1 and rest of it is wired connection. Thus, if the wireless delay and wired delay is ω and ϖ, then

$$\tau = \omega + \varpi \tag{1}$$

Here, Eqn. (1) can have two variations. Let, τ_{WLAN} and τ_{CDMA} be the time taken to send a packet from an MH to the CN through a WLAN and a CDMA wireless network, respectively. When the wireless network is WLAN, we calculate τ_{WLAN} with wireless delay of WLAN, ω_{WLAN}, and when the wireless network is CDMA, we calculate τ_{CDMA} with wireless delay of CDMA, ω_{CDMA}.

ω depends on wireless technology. For WLAN, ω is derived in [18] as

$$\omega_{WLAN} = E[\hat{a}]E[T_{slot}] \tag{2}$$

where $E[\hat{a}]$ is average number of slot time required for a successful transmission and $E[T_{slot}]$ is the slot time.

Let, P_{tr} be the probability of at least one packet transmission during a random slot time, P_{suc} is probability of one successful packet transmission, P_{col} is probability of a collision, W = minimum window size of exponential backoff algorithm and m is the maximum backoff stage. Then, $E[\hat{a}]$ for WLAN is derived in [18] as

$$E[\hat{a}] = \frac{(1-2P_{col})(W+1) + (P_{col})^W(1-(2P_{col})^m)}{2(1-2P_{col})(1-P_{col})} \tag{3}$$

and $E[T_{slot}]$ as

$$E[T_{slot}] = (1-P_{tr})\kappa + P_{tr}P_{suc}T_{suc} + P_{tr}(1-P_{suc})T_{col} \tag{4}$$

If we assume, data collision is not sensed by the receiver, essentially, $T_{suc} = T_{col} = T_{packet}$ where T_{packet} is time to send a packet. For WLANs,

$$T_{packet} = T_{sense} + T_{CTS} + T_{RTS} + 3T_{SIFS} + T_{DIFS} + \frac{1}{\mu\beta_{WLAN}} + T^{prop}_{WLAN} \tag{5}$$

where T_{sense} is channel sensing and backoff time, $\frac{1}{\mu}$ is average packet size, β_{WLAN} is the WLAN bandwidth, and T_{CTS}, T_{RTS}, T_{SIFS} and T_{DIFS} are the CTS, RTS, SIFS and DIFS time, respectively, in WLAN MAC and can be obtained as $\frac{standard\_message\_size}{\beta}$. $standard\_message\_size$ represents the corresponding message size. Propagation delay, T^{prop}_{WLAN} is negligibly small compared to other delays. Substituting Eqns. (3) and (4) in Eqn. (2) to calculate ω_{WLAN}.

On the other hand, delay in a CDMA network, ω_{CDMA}, is derived in [19] as

$$\omega_{CDMA} = \frac{\omega^{MIN}_{CDMA}}{1 - P_{pe}} \tag{6}$$

where P_{pe} is the probability of packet error and ω^{MIN}_{CDMA} is the minimum delay for a packet. ω^{MIN}_{CDMA} is comprised of transmission and propagation delay. The propagation delay, T^{prop}_{CDMA} is CDMA is very low and can be approximated as 3 ms [19]. On the other hand, transmission delay, $T^{trans}_{CDMA} = \frac{1}{\mu\beta_{CDMA}}$ where $\frac{1}{\mu}$ is average packet size and β_{CDMA} is the bandwidth for CDMA network. Then,

$$\omega^{MIN}_{CDMA} = T^{prop}_{CDMA} + \frac{1}{\mu\beta_{CDMA}} \tag{7}$$

Eqn. (7) can be used in Eqn. (6) to calculate ω_{CDMA}.

Now, wire delay, ϖ, is the delay on the route from the gateway to the CN. Let, there be N links in this route. Then,

$$\varpi = \sum_{i=0}^{N-1} (T^{prop}_i + T^{trans}_i + T^{proc}_i) \tag{8}$$

where T^{prop}_i, T^{trans}_i, and T^{proc}_i are propagation, transmission, and processing delay on link i. If length, capacity and flow on link i is L_i, β_i, and λ_i, then $T^{trans}_i = \frac{1}{\mu\beta_i}$, $T^{prop}_i = \frac{L_i}{C}$, and $T^{proc}_i = \frac{1}{\mu\beta_i - \lambda_i}$. So, Eqn. (8) can be expressed as

$$\varpi = \sum_{i=0}^{N-1} (\frac{1}{\mu\beta_i} + \frac{L_i}{C} + \frac{1}{\mu\beta_i - \lambda_i}) \tag{9}$$

where C is the speed of light on the medium and arrival and departures are independent.

mSIGMA performs soft handoff [14]; while the CN starts sending the packets to the new IP address, the old packets are delivered to the MH using the old IP address. So, inter-class handoff time, as defined earlier in this section, for mSIGMA is the differential delay between the two networks. So, the handoff time for mSIGMA is

$$\delta T^{mSIG}_{W\leftrightarrow C} = |\tau_{WLAN} - \tau_{CDMA}| + H_P \tag{10}$$

where H_P is the handoff processing time at CN. Here, τ_{WLAN} and τ_{CDMA} can be evaluated from Eqn. (1). If we assume, wire-line part of WLAN and CDMA network has same number of links with similar network properties, then Eqn. (10) can be simplified as

$$\delta T^{mSIG}_{W\leftrightarrow C} = |\omega_{WLAN} - \omega_{CDMA}| + H_P \tag{11}$$

We can evaluate Eqn. (11) using Eqns. (2), (6) and (9).

2) Handoff Time of Mobile IP: Mobile IP (MIP) [12] is the IETF solution for mobility that performs hard handoff [14]. Vertical handoff schemes, such as MIPL, OmniCon, Gateway Based and Policy Enabled are based on MIP [13]. For MIP, when an MH changes its subnet, the packets are sent to the subnet 1, or home network (HN), where the connection is initiated and from there the packers are being forwarded to the current subnet, or the visiting network (VN). So, for MIP, for HN, $\tau_H N = \tau$, as shown in Eqn. (1). But, for VN, the wired part is twice as the packets destined to VN come the gateway of subnet 1 first. So, for VN, we have

$$\tau_{VN} = \omega + 2\varpi \tag{12}$$

Here, if subnet 1 is WLAN, then $\omega = \omega_{WLAN}$ in τ_{HN} and $\omega = \omega_{CDMA}$ in τ_{VN}. On the other hand, if subnet 1 is CDMA, this is other way round.

As MIP performs hard handoff, when the packets are forwarded to the VN, all the on-the-fly packets destined to HN cannot be delivered. So, the inter-class handoff time for MIP is

$$\delta T^{MIP}_{W\leftrightarrow C} = \tau_{VN} - \tau_{HN} + H_P \tag{13}$$

If we substitute the values of τ_{HN} and τ_{VN} in Eqn. (13), we obtain

$$\delta T^{MIP}_{W\leftrightarrow C} = |\omega_{WLAN} - \omega_{CDMA}| + \varpi + H_P \tag{14}$$

B. Analytical Model for Packet Loss

As mSIGMA performs soft handoff, when the MH changes its subnet and changes IP address, all the packets destined to the MH using the previous IP address is delivered. So, packet loss due to handoff is minimized. But, still there can be packet loss if the handoff time is larger than the low signal time, σ. Low signal time can be defined as the time when the signal strength of the AP at a subnet goes below a threshold where it becomes too weak to receive data correctly. So, for mSIGMA, packet loss takes place if $\delta T^{mSIG}_{W\leftrightarrow C} > \sigma$. So, loss time for mSIGMA,

$$T_L = \delta T^{mSIG}_{W\leftrightarrow C} - \sigma \tag{15}$$

Now, if S_{low} and S_{zero} are the locations where signal is below the threshold and non-recoverable, respectively, then the low signal time can be calculated as

$$\sigma = \frac{|S_{low} - S_{zero}|}{v} \tag{16}$$

where v is the linear velocity of MH. Then, if the packet arrival rate at MH is λ_M, then packets lost for mSIGMA is

$$L^{mSIG}_{pack} = \lambda_M \sigma \tag{17}$$

On the other hand, for hard handoff, all the on the fly packets are lost. So, the packets sent to the old IP address during the handoff is lost. So, the packet loss for MIP during an inter-class handoff is

$$L_{pack}^{MIP} = \lambda_M \delta T_{W \leftrightarrow C}^{MIP} \quad (18)$$

IV. Illustrative Examples

Here, we present performance analysis of mSIGMA using analytical model described in Sec. III and experimental results from our test-bed.

A. Performance Evaluation from Analytical Model

We analyze the performance of mSIGMA against MIP. We give a set of standard values to the following variables as described in [20]: $\frac{1}{\mu}$ = 1536 bytes, T_{SIFS} = 10 μsec, T_{DIFS} = 50 μsec, T_{CTS} = 203 μsec, T_{RTS} = 207 μsec. We consider standard values, T_{sense} = 50 μsec. We assume, 10% of time there is not a packet available for transmission and 20% of time packets end up in collision. Considering IEEE 802.11b standard for WLAN, we set W = 32 and m = 5. We consider 500 Kbps data rate for CDMA, average number of wired hops as 10, average link length as 100 km with 100 Mbps bandwidth. We approximate $C = 3 \times 10^8$.

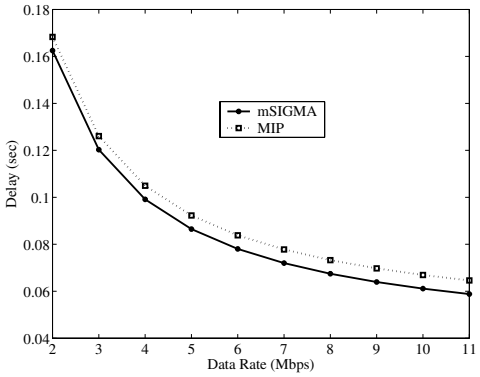


Fig. 3. Handoff delay for different data-rate of WLAN.

Figure 3 shows handoff delay for mSIGMA and MIP for inter-class handoff for different WLAN data rate. As supported by IEEE 802.11b standard for WLAN, the data rate is varied from 2 Mbps to 11 Mbps. We observe that for any data rate, mSIGMA has lower delay than MIP. We also observe that for lower data rate, MIP performs closely to mSIGMA but as data rate increases, difference in delay for MIP and mSIGMA keeps increasing. Thus, for today's high speed wireless network, mSIGMA ia more appropriate solution for inter-class handoff.

Figure 4 shows the delay for MIP and mSIGMA for different collision probability. Here, we consider a 2 Mbps data rate for WLAN and we vary the collision probability from 10% to 40%. We can see that as collision probability increases, the average handoff delay in the network increases. We also observe that mSIGMA has lower delay than MIP with both high and low collision probability. So, in a congested contention based system, mSIGMA can perform inter-class handoff with lower delay than MIP.

Figure 5 shows the packets lost during handoff for MIP and mSIGMA. We can observe that mSIGMA can perform handoff with lower losses than MIP for both high and low arrival at an

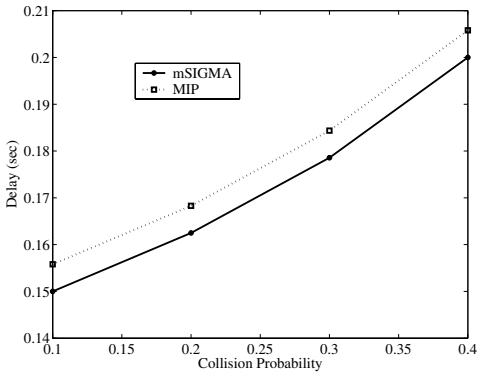


Fig. 4. Handoff delay for different collision probability.

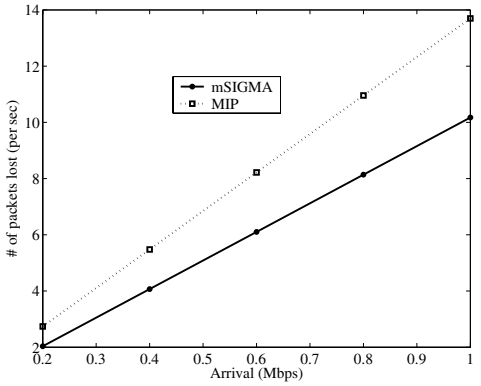


Fig. 5. Packet loss for different arrivals at MH.

MH. We also see that as the arrival rate increases, packet loss for MIP increases more rapidly than mSIGMA. So, as the end users, i.e., MHs are using more bandwidth hungry applications, the requirement of performing handoff with higher arrival rate is becoming more important. Thus, mSIGMA can perform inter-class handoff for such end users with lower packet loss.

B. Performance Evaluation with Experimental Setup

In our experimental setup, we have used IEEE 802.11b WLAN with 2 Mbps data rate and used Sprint's network to connect to CDMA. The MH used in the experiment was equipped with two interface cards; one was a internal Intel 2200-bg WLAN card and the other one is a Sprint PC-5740 card to connect to the CDMA network. We have used D-Link routers to setup WLAN environment in Telecom and Networks Research Lab at University of Oklahoma, Norman to test inter-class handoff of mSIGMA. We have used FTP style continuous data transmission between an MH and a CN. The WireShark application was used to capture the performance data.

Figure 6 illustrates the throughput of the data communication measured at the MH. The CN streams data to the MH continuously and MH performs an upward and a downward handoff while receiving data from CN. Here we can see that even for difference in bandwidth, with mSIGMA, the throughput during handoff does not go to zero.

We can see that between 34.2512 and 34.4257 seconds, the handoff from WLAN to CDMA has occurred. As the

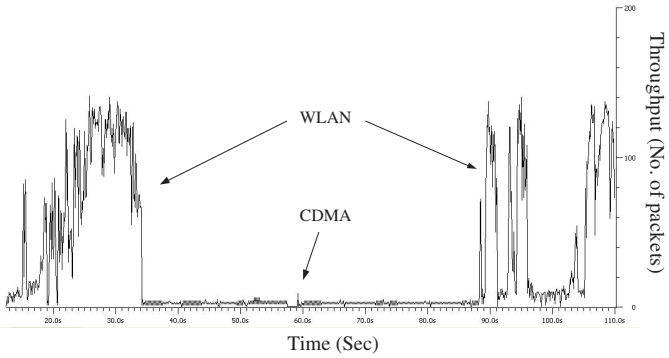
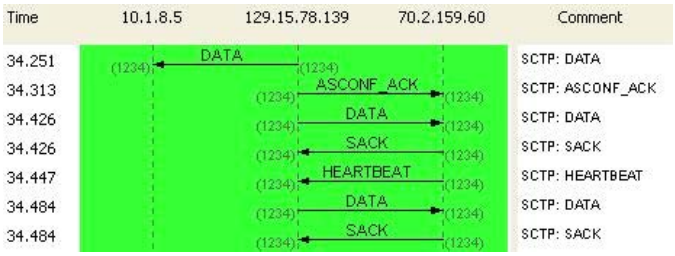
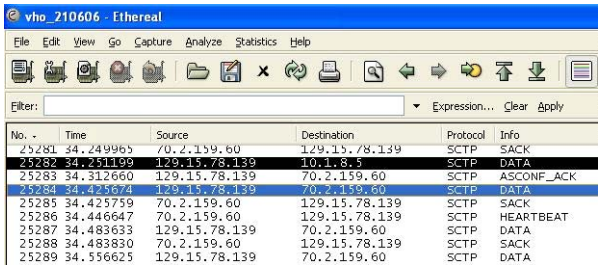


Fig. 6. Throughput against time for vertical handoff between 802.11 WLAN and Sprint CDMA.



Signalling diagram



Ethereal capture of data flow and signalling

Fig. 7. Vertical handoff from 802.11 WLAN to Sprint CDMA.

bandwidth of CDMA is very low compared to WLAN, a significant reduction of throughput can be observed. This is more illustrated in figure Fig.7.

This handoff can be observed by watching the change of direction of packets. We can observe that packet from CN (129.15.78.139) coming to WLAN (10.1.8.5) is switched to CDMA (70.2.159.60). In the WireShark capture in Fig. 7, the last packet to the WLAN is highlighted in black and the first packet to CDMA is highlighted in blue (colored figures are shown in [17]). From here, we can observe that the time taken for upward handoff is 0.17 seconds.

V. Conclusion

A multi-class network is comprised with a combination of heterogeneous networks where multiple homogeneous network can exist as neighbors. In a multi-class network, a mobility management scheme needs to be able to perform both inter-class (vertical) and intra-class (regular) handoff. Here, we propose a mobility management scheme, mSIGMA for multi-class network that can perform both kinds of handoff. Then, we have presented a analytical model for mSIGMA and compared its performance with IETF solution, MIP. Our performance evaluation illustrates that mSIGMA has lower delay and packet loss than MIP for inter-class handoff. We also show the efficiency of mSIGMA using experimental setup. We show that mSIGMA can perform inter-class handoff in 0.17 seconds without blocking the throughput.

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