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Packet Striping for Multi-Interfaces

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Abstract- In future mobile systems, the end-terminals will be considerably more diverse than nowadays, and the users will have a greater choice of access technologies, offering different QoS, cost, security and so on. A mobile terminal equipped with multiple interfaces can achieve a much higher bandwidth by aggregating the bandwidth offered by the individual networks. In this paper, we present a system based on Mobile IPv6 that achieves the above objectives. We will discuss in detail the architectural requirements and algorithms that are needed to support the above system. We also extended our proposed scheme to support even if the correspondent node also has multiple interfaces. Simulation results show that the proposed algorithm can uniformly distribute data packets among multiple channels and deliver the packets perfectly in order at receiver to achieve bandwidth aggregation.

Keywords- Network Striping, Interface Selection

I. INTRODUCTION

Nowadays, more and more portable terminals have the ability to connect to the Internet using a wide range of access technologies, such as Third Generation (3G) cellular networks, General Packet Radio Service (GPRS), IEEE 802.1 la/b/g, and Bluetooth. It is foreseen that the Internet Protocol (IP), particularly MobileIP version 6 (MIPv6), will be the convergent layer when these terminals connect to the Internet. Future Fourth Generation (4G) terminals will access one or more of the above wireless technologies using multiple interfaces simultaneously, which extends the power of mobile terminal both in terms of coverage area and bandwidth.The use of multiple access interfaces ([1]), either in fixed or mobile nodes, can bring various benefits to the users. The major challenges that needs to be solved in this multi-homed Mobile Node (MN) includes, which flow (data corresponding to a single application) should be mapped to which interfaces and if a flow is mapped to multiple interfaces how to properly distribute packets to different interfaces for efficient communications. Splitting traffic over multiple links is commonly referred to as packet striping ([2]). Different network links have different bandwidths and delays. If data packets are not distributed properly, it may result in one network link being congested while another link is under-utilized. Another problem in load sharing is out-of-sequence packet reception at the destination node or correspondent node (CN) due to unequal delays of different links.

The rest of the paper is organized as follows. Section II. describes the related work in this area. Our proposed 4G Terminal Architecture is specified in section III. The Interface Selection Algorithm and Mapping Algorithms are described in section IV. and V. respectively. Simulation Results are presented in section VI. followed by conclusions in section VII.

II. RELATED WORK

There are a growing number of activities related to the selection of a best network for a flow and scheduling of packets using multiple interfaces simultaneously in 4G terminals. In the following subsections we present some of the most relevant part of this research.

A. *Interface Selection and Mapping Algorithms*

In a heterogeneous network, the choice of the “best” network can be challenging; for example, an in-building RF network with a weak signal may yield better performance than a wide-area data network with a strong signal. Finally, there may also be financial differences that do not arise in a single network; some networks may charge more than another for a particular service. Many selection decision algorithms are defined in the literature in the context of vertical handoff. Selection decision algorithms in vertical handoff considers the entire mobile terminal as one unit and the decision is to decide to which network a hand-off is to take place. But within a terminal we may wish to consider the handoff of each application separately. A survey of network selection algorithms in a heterogeneous environment is described in [4]. A selection decision mechanism for terminals using profiles is described in [5], but it is too complex for small mobile terminals like a PDA.

A single interface may not be able to satisfy the complete bandwidth requirements of an application. So, an application may need to be mapped to more than one interface. We do not face this type of problem in case of vertical handoff decision algorithms as it is a many-to-one problem i.e. all applications are mapped to a single interface only. But in multi-interface terminals it is a many-to-many problem i.e. multiple applications are mapped to multiple interfaces. Thus the purpose of a Mapping Algorithm is to solve this problem. No one seems to have concentrated much on this problem. So, we have proposed a combination of SDF (Q^i_a) and Mapping Algorithm to address this issue.

B. Scheduling Algorithm for Multiple Interfaces

A scheduling algorithm needs to partition the traffic from multiple input queues (corresponding to each application) onto multiple output links (corresponding to each interface). This objective can be achieved by combining a fair queuing algorithm ([3]) (which partitions traffic from multiple input queues onto a single output link) with a channel striping algorithm ([6]) (which partitions traffic from a single queue onto multiple links). The Stripe protocol ([6]) can be used as the channel striping algorithm but it was designed under the assumption that the links offer FIFO delivery. This results in a penalty in the form of synchronization between sender and receiver in case of packet loss and also results in large delay and jitter.

A packet-striping algorithm, in which the data packets are transmitted out of order at the sender side is specified in [7], so that there is greater possibility of in-order reception at the receiver side. Reference [8] proposed an algorithm that combines the Weighted Round Robin (WRR) with Jump Ahead (JA) packet selection ([7]) to distribute packets uniformly among multiple interfaces but packets may arrive out of order at the receiver.

A scheme for utilizing multiple network interfaces is introduced in [9]. When a packet is to be sent, Earliest Delivery Path First (EDPF) algorithm is employed to select the network interface that can minimize the expected arrival time of the packet. The advantage of this is that absolutely zero buffer size is required at the receiver end. Even though it has the best performance for a single application flow, it fails to distribute traffic uniformly on all links when we have multiple flows with different QoS requirements. It fails as it considers only delivery time of the interfaces but not all the QoS requirements of the flow. Finally, more number of calculations are required as the delivery time has to be calculated for each and every interface and for each packet.

So, we have extended the WRR-JA to achieve perfect in ordering as it can distribute packets uniformly and supports multiple applications with different QoS requirements unlike EDPF.

No one seems to have considered the case when the CN is able to receive on multiple interfaces. So, we have extended our packet striping scheduler (WRR-LA) to solve this issue.

III. THE PROPOSED 4G TERMINAL ARCHITECTURE

In a multi-interface handheld without support, and with the presence of multiple access networks, a user has to manually choose from one of many alternatives. Clearly this is not satisfactory. We propose a scheme that takes into account multiple flows in a handheld (emanating from different applications), and also takes into account the presence of multiple network interfaces. Our scheme determines which flow should be mapped to which interfaces and if a flow is mapped to multiple interfaces how to properly distribute packets to different interfaces. The access networks capabilities, the profile of the flows, and user feedback are inputs to our scheme. Fig. 1 shows the envisaged mobile terminal architecture, its components and the possible interactions amongst them.

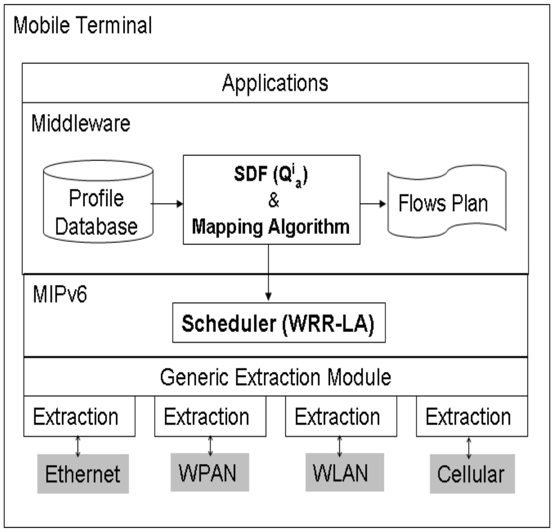

Fig. 1: Proposed 4G Terminal Architecture

Each access network specific Extraction Module will gather the type of service provided by respective service provider. This information is passed to the Generic Extraction Module which stores this information in the Profile Database in a structured way. The Selection Decision Function (SDF) & Mapping Algorithms will use this information and specify which application flows should be mapped to which interfaces. These results are stored in the Flows Plan list array for each application flow, which is used by the scheduler(WRR-LA) to distribute the packets uniformly among respective channels assigned to that application and deliver the packets in order to the CN. The architecture is split into various functional units because this modular design facilitates implementation and testing and it also permits the gradual integration of better selection decision algorithms, novel network detection and monitoring techniques, and new interfaces. To ensure that different applications running on a terminal get a fair their share of the available bandwidth, we combined our packet striping scheduler WRR-LA with a fair queuing algorithm like Weighted Fair Queuing (WFQ). We also extended our proposed scheme to support the case when even the CN has multiple interfaces. The following figure describes how the packets of multiple application flows are mapped to multiple interfaces.

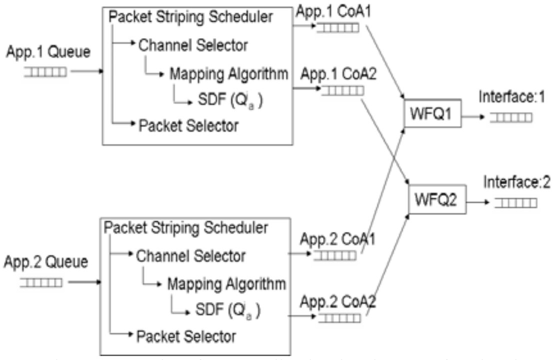

Fig. 2: Data Flow from Application level to Interface level

Assume there is a unique Care of Address (CoA) assigned for each interface of the MN. When an application generates a new packet it is placed in the respective application queue. Packet striping scheduler will run only when any of the application CoA queues (a queue which is assigned for an (application, CoA) pair) are empty. The purpose of placing packets in the application queue instead of applying scheduling immediately when packets arrives is to consider dynamically changing environment. Finally to make sure that all application will get their fair share of bandwidth all applications CoA queues for a single interface are connected to the respective output interface queue by WFQ. The details of each component are explained in the following sections.

IV. INTERFACE SELECTION ALGORITHM

The services offered by any network can be associated with the following parameters.

a. Cost of service (C)
b. Security (S)
c. Bandwidth (B)
d. Bit Error Rate (E)
e. Range (R)
f. Power requirements (P)

We assume that these parameters are provided by network operators (for example, QoS profile in GRPS). When a new access network is detected, these parameters are added to the database. Further, for each application, minimum required bandwidth (Bmin) and the relative preferences for the parameters for different networks, is assumed to be known and this information also forms part of the database. All of this information acts as input to the SDF to select the best network for a flow.

Let C_i, S_i, B_i, E_i, R_i, P_i be numerical scores for the parameters in network/interface 'i'. Similarly, let W_C, W_S, W_B, W_E, W_R, W_P be the relative weights for each of the above parameters for a particular application. Each weight is proportional to the significance of a parameter in the selection decision function. Each application 'a' will have different weights. The values of the weights range from $0 \leq W_X \leq 1$, and the total of all the weights must be equal to 1. We know that Security, Bandwidth and Range need to be higher whereas Cost, Bit Error Rate and Power Requirement need to be lower. So, given a set of parameters and a set of weights we can estimate the quality obtained by an application 'a' when it is mapped to interface 'i' is as follows:

$$\begin{aligned} Q^i_a &= f(W_C, C_i, W_S, S_i, W_B, B_i, W_E, E_i, W_R, R_i, W_P, P_i) \\ &= W_C/C_i + W_S*S_i + W_B*B_i + W_E/E_i + W_R*R_i + W_P/P_i \end{aligned}$$

For example, consider two networks in which one network is providing (30C,100S,20B,0E,50R,10P) service and the other network is providing the service (20C,0S,20B,0E,50R,10P). If an application has the weights (0.1C, 0.9S, 0B, 0E, 0R, 0P) (it is an application with high security requirements), then our SDF (Q^i_a) value is high for the first network as it is more secure than the second. This interface selection algorithm is used by the following mapping algorithm.

V. MAPPING ALGORITHM

At MN, when a new flow is being initiated we need to map it to the best network(s) currently available. But there are two possible cases in interface selection:

i. There are one or more interfaces, each of which can satisfy the flow's data rate requirement alone. Among the qualified interfaces, the one with the highest Quality calculated using Q^i_a (specified in section 4) will be selected for carrying the traffic of the flow, so that the application is mapped to the best network to suit its requirements.
ii. No interface meets the bandwidth requirement alone. When the expected data rate of the flow exceeds the available bandwidth of any single interface, a set of interfaces will be selected; whose aggregated bandwidth can meet the requirement.

When a flow is mapped to a single interface we don't have any problem at the destination side. But when it is mapped to multiple interfaces, packet reordering problems will occur at the destination node. This problem can be solved using our proposed packet striping scheduler (WRR-LA).

One point that needs to be noted here is that when splitting connections onto multiple links, the aggregated bandwidth perceived by the connection is usually less than the sum of the bandwidths on the different links. Therefore the bandwidth input to the algorithm must be made slightly higher than required.

The following algorithm describes how to select the set of suitable interfaces for a given data flow.

```
M:   The set of interfaces that are mapped to the data flow.
A:   The set of available interfaces that are not in M
$BW_i$:  Available bandwidth that can be provided by interface 'i'
$ISL_a$:   Interface Selection List for an application 'a' (Stored in "Flows Plan" component)

$M \leftarrow \varphi$;
For each application flow 'a'
{
  $ISL_a \leftarrow \varphi$;
  DR:  Data rate requirement of the flow 'a'
  s: Unsatisfied data rate requirement of the flow 'a'
  $s \leftarrow DR$;
  while $A \neq \varphi$ and $s > 0$ do
    if $\exists k \in A, BW_k \geq s$ then
      Select interface j, where $BW_j = \max \{Q^i_a \mid i \in A\}$;
        allocated = s;
    else
      Select interface j, where $BW_j = \max \{BW_i \mid i \in A\}$;
        allocated = $BW_j$;
    end if
    $BW_j = BW_j$-allocated;
    if $BW_j = 0$ then
      $M \leftarrow M \cup \{j\}$;
      $A \leftarrow A / \{j\}$;
    End if
    $s \leftarrow s -$allocated;
    $ISL_a = ISL_a \cup \{j, \text{allocated}\}$;
  end while
}
```

VI. SIMULATION RESULTS

Our proposal consists of three main components. These are, the interface selection policy, SDF (Q^i_a), the Mapping Algorithm and the Packet striping scheduler (WRR-LA). Among these we need to evaluate the performance of only the packet striping scheduler because SDF and mapping algorithms are simple heuristic functions/algorithms. So, we conducted a series of simulations to evaluate the performance of our proposed packet striping scheduler algorithm to check whether it is distributing packets uniformly and delivering packets in order to the destination.

The scenario setup consists of two nodes. One is the MN that has three network interfaces, and the other is the CN that has one network interface. Assuming that Mobile IPv6 route optimization is effective, the MN can directly send data to the CN without routing it through the Home Agent. The MN can send packets to CN via three different paths, each of which corresponds to one of the MN's multiple interfaces. The bandwidths and propagation delays associated with the different paths are specified as:

- path1: 100*Kbps,* 200*ms*
- path2: 1*Mbps,* 20*ms*
- path3: 2*Mbps,* 5*ms*

The purpose of considering this type of setup is that this path setup approximates the network characteristics of GPRS,Bluetooth and IEEE 802.11 WLAN respectively. As our main focus was on the packet striping scheduler we assumed the following. We assumed all networks are under the control of a single administrative domain. We assumed that there was only one application flow rather than multiple flows. We assumed that the source traffic is exponentially distributed, with the average data rate of 3*Mbps*, which is close to the limit of the three links' aggregated bandwidth. We also assumed that the MN sends only fixed-sized packets to the CN. Finally, we have not simulated WFQ in our simulation as there is only one application flow.

The performances of the following five load-sharing algorithms are evaluated:

i. Earlier Delivery Path First (EDPF): Schedule a packet on a channel which delivers the earliest.
ii. Weighted Round Robin –Look Ahead (WRR-LA): Our Proposed Scheme
iii. Weighted Round Robin –Jump Ahead (WRR-JA): Weighted Round Robin with Jump Ahead
iv. Weighted Round Robin (WRR): output channels are selected in WRR manner, but outgoing packets from the queue are transmitted in FIFO order.
v. Round Robin (RR): output channels are selected alternately in simple RR manner, but outgoing packets from the queue are transmitted in FIFO order.

These algorithms are compared based on two metrics: buffer requirement and average delay.

A. Buffer Requirement

In our simulation, when the receiver receives out-of sequence packets at the transport layer, it stores the packets in a buffer and waits for the preceding packets to arrive. The packets in the buffer are passed to the upper layer when the gaps are filled up, so that user applications experience in sequence packet reception. The buffer size requirement depends on the amount of out-of-sequence packets received. The greater the amount of out-of-sequence packets, the larger is the requirement of buffer space. Fig. 6 shows the simulation result of the buffer requirements under different packet sizes.

Packet Size(Bytes)	EDPF	URS	RR-JA	RR	RR

100	0	0	1.9	4.1	9.72
200	0	0	3.6	7.0	9.82
300	0	0	5.7	9.8	9.77
400	0	0	7.6	2.8	9.68
500	0	0	9.5	5.5	9.8

Table1: Re-Sequencing Buffer Requirement

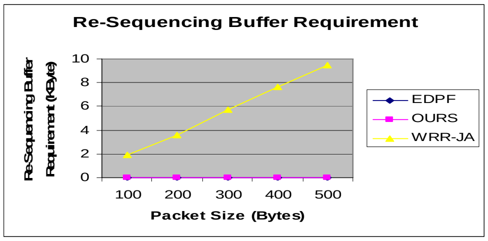

Fig. 6: Re-Sequencing Buffer Requirement

RR scheme displays the worst performance due to unbalanced packet distribution. The weakest link is heavily congested, which results in a high volume of out-of-sequence packets. WRR and WRR-JA perform much better than RR due to fair traffic distribution. Our Proposed Scheme, WRR-LA outperforms WRR-JA in buffer requirement. This shows that WRR-LA packet scheduling effectively increases the chance of in-sequence packet reception. EDPF also requires zero buffers but packets are not uniformly distributed as in WRR-LA.

B. *Packet Delay*

Here, packet delay refers to the delay experienced by the upper-layer application, which includes link transmission time, propagation delay, and queuing time in the re-sequencing buffers. The measured packet delay for different packet sizes is illustrated in Fig. 7.

Packet Size(Bytes)	PF	URS	RR-JA	RR	RR
100	5	17	19	04	3288
200	6	18	22	08	3294
300	6	19	25	3	3297
400	7	20	28	7	3297
500	8	21	31	2	3311

Table 2: Average Packet Delay

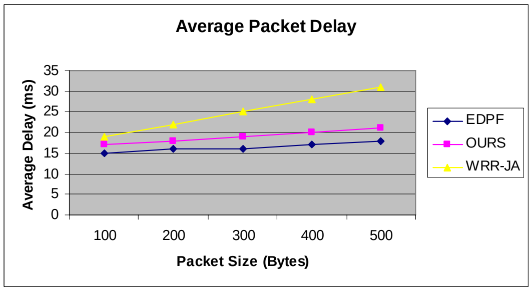

Fig. 7: Average Packet Delay

The long delay in RR scheme is mainly caused by congestion on the slow path. A shorter delay against WRR is the result of shorter queuing time in re-sequencing buffer at the receiver. Again, OUR proposed scheme outperforms WRR-JA. But its delay is more than EDPF because as we are distributing packets among the interfaces in the ratio of the bandwidths and slower links takes more time.

Clearly therefore, for a single application flow, EDPF has the best performance. But in a realistic scenario where multiple flows with different QoS requirements will contend for the available bandwidth, a flow will have to be distributed among the multiple available interfaces in a fixed manner.

VII. CONCLUSION

In this paper we have presented an adaptable and reconfigurable architecture for mobile terminals supporting multiple access network interfaces. The proposed architecture includes adaptation mechanisms and relies on tight interactions amongst the different layers, from the application layer to the data link layer. Our first aim is to allow the user to always stay connected through the best access network. So, we have described an interface selection policy and a mapping algorithm to map the applications flows to the best access networks currently available. Our second goal is to distribute packets uniformly and in order to the destination, among the interfaces currently available. So, we have presented a multi-homed system that supports load-sharing among multiple network interfaces so that the MN can enjoy the aggregated bandwidth.

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