A Policy Oriented Multi-Interface Selection Framework for Mobile IPv6 Using the ID/Locator Split Concepts in the Next Generation Wireless Networks

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Abstract—**Next Generation Wireless Networks (NGWNs) will be the convergence of fixed and mobile networking technologies, e.g., Ethernet, Wireless LAN, 2G/3G/4G, etc. This united ubiquitous network will consist of billions of mobile devices, each with multiple networking interfaces. These interfaces may belong to a set of diverse link layer technologies. Internet Protocol (IP) shall potentially be used as the inter-networking protocol to bridge this diversity in the underlying wireless link-layer similar to the present wired Internet architecture. However, the traditional IP was not designed for wireless environments and, hence, faces several issues in mobility, multihoming, user path selection, etc. The basis of most of these issues lies in the problem of contextual overloading of IP addresses to serve as both locators and identifiers. The ID/Locator Split concept is a well-known approach to overcome this problem. Mobile IPv6 can be considered as an example of an ID/Locator Split mechanism in which the home address is used as the identity of the mobile node and its care-of-addresses (CoAs) are used as locators. Cellular networking standards organizations, e.g., the 3rd Generation Partnership Project (3GPP), have adopted the Mobile IP concept for next generation cellular networks to maintain the mobility in an all-IP network framework. Mobile IPv6 and its optimizations can achieve full mobility and deployability. Currently, Mobile IPv6 allows features such as multiple CoA registrations and flow binding options. Apart from mobility, these extensions provide a solution for user-multihoming. However, there is no standard mechanism to select the proper interfaces or to map CoAs underneath. In this paper, we propose a policy-based QoS framework for users to choose the best *N* interfaces that suit the requirements of their specific applications.**

***Keywords-** Mobile IPv6; Policy; Multi-Interface Selection; Mobility; Multihoming; ID/Locator Split; NGWN; Flow Striping; Flow Distribution; Flow Binding; Next Generation Wireless Networks, Future Cellular Networks*

I. INTRODUCTION *(HEADING 1)*

Next Generation Wireless Networks (NGWNs) will need to realize the convergence of different wireless technologies and at the same time be interoperable with traditional IP-based wired networks. In NGWNs, the nodes or hosts tend to be mobile; they can freely move or change their locations at high speed. In such a mobile wireless environment, the channel capacity is not constant over time and distance. Short-time disruptions may occur more frequently and result in a disconnection of operation. Thus, *mobility* is clearly one of the key requirements for the NGWNs.

With the advance of networking technologies, the concept of a single host - single interface - single network shall no longer be true in NGWNs. A node or host may have many different networking interfaces incorporating different types of quality of service (QoS) controls such as cellular networks (2G/3G/4G) and wireless broadband networks (e.g., WiMAX and LTE) for various applications including voice, video, games, etc. This *multihoming* phenomenon offers many advantages such as seamless mobility (handover/handoff), enhanced availability (fault tolerance), and traffic engineering (load balancing and load sharing).

In NGWNs, the network will be more user-centric. The users will be allowed to make their decisions for preferred paths through *user path selection mechanisms* (based on the price paid and its corresponding QoS). Different paths may correspond to different networking interfaces. The service provider should provide useful information with inherent security to aid such mechanisms.

The user path selection and/or networking interface selection decision may be guided by several factors and limited by many constraints such as 1) modes of operation - battery or power-line, 2) application requirements (e.g., required throughput, maximum delay, and completion time), 3) economic viability - per min or flat rate, etc. Therefore, there is no clear solution on how to choose the proper networking interfaces to make use of the resources, i.e., bandwidth, efficiently and also meet the user requirements and constraints.

Consider the communication among nodes or users in NGWNs. Internet Protocol (IP) is a well-known networking protocol used in both wired and wireless networks. The 3rd Generation Partnership Project (3GPP) [1] has decided to use IP for the next generation of cellular wireless networks; System Architecture Evolution (SAE) is the core networking architecture and SAE is all-IP based.

One of the greatest issues of the current IP architecture is *the overloading of IP address semantics* [2, 3], that is, the IP address acts as a host or node identifier and a locator in the routing space. This contextual overloading implicitly binds a host to its point-of-attachment into the network, and there is no independent namespace to represent the end host itself. Thus, every time the end host moves to a new network and

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obtains a new IP address, it has to do a network handover, and all the sessions interfaced to the previous IP address are broken. Such an implicit overloading makes it difficult to support full mobility, multihoming, traffic engineering, etc.

In this paper, we apply the ID/Locator Split idea [2, 3], a well-known approach used to resolve the mobility and multihoming issues, into a Mobile IP environment. As in [4], Mobile IP [5, 6] is treated as one of the ID/Locator Split schemes in that the Mobile IP home address (HoA) is used as the node identity and its care-of-address (CoA) as the locators. A home agent (HA) is a rendezvous server or the mapping server to resolve the identity from/to the locators. This separation makes Mobile IP support those features.

However, in ID/Locator Split schemes, Mobile IP in particular, there are no mechanisms to make use of multiple interfaces in terms of traffic engineering and/or user path preference to utilize the multihoming feature. Thus, in this paper, we also propose an approach to use multiple interfaces simultaneously in a Mobile IP environment. Note that the proposed techniques can also be used in other ID/Locator Split schemes with some modifications such as including a flow identification feature.

In addition, consider Mobile IPv6, recently multiple CoAs registrations [7] and flow binding options [8] have been proposed. These combinations allow Mobile IPv6 to achieve *per flow* multihoming in terms of flow sharing and flow balancing. Nevertheless, neither provides a mechanism to map or select a proper flow into each interface using path characteristic information. Thus, in this paper, we introduce the policy-based multiple interface selection to choose the best N interfaces and/or paths to meet the user requirements and constraints.

This paper is organized as follows. In Section II, we briefly describe the general concept of ID/Locator Split applied to a Mobile IP environment with multihoming. In Section III, we describe some related work on interface selection and flow distribution problems. Then, in Section IV, we introduce a policy-based QoS model used to select the networking interface(s). The results are used to choose N best interfaces and/or paths. In Section V, we describe the functionality of a connection manager used to support the policy-oriented QoS model. Finally, the conclusions and future work are discussed in Section VI.

II. MOBILE IPV6 USING ID/LOCATOR SPLIT

The ID/Locator Split concept [2, 3] is a well-known approach used to resolve both mobility and multihoming issues. Basically, the idea is to separate the functionality of the identity from that of the locator. Each mobile node (MN) or host has its own unique identity. When the node moves, its identity does not change, but its locator does. The locator represents the current point of attachment to the network.

Several proposals have been introduced using the ID/Locator Split concept such as HIP, SHIM6, MILSA, LISP, etc [2, 3]. The main differences among these techniques are their varying focuses on the different protocol layers, on the introduction of new naming spaces, on the required changes in protocol stack, on where the splitting occurs, and on the ways to separate a host's identity from its locator.

As in [4], we consider Mobile IP as one of the ID/Locator Split schemes in that 1) the splitting is at the end host, 2) its focus is on the network layer, 3) there is no new naming space required (for deployability purpose), and 4) no change is required in the protocol stack. When the MN is not in its home network, the MN's HoA is considered as the node identity and its CoAs as the locators. The HoA is not changed when the MN moves from one network to another but not its locations (CoAs).

Mobile IPv6 functions as follows: the MN's HoA is used as the node's identity. When the MN moves from one network to another network, the MN informs its home network about its new IP address (CoA). In case a correspondent node (CN) wants to contact the MN, the CN sends packets to the home network; the packet is intercepted by the HA and forwarded to the MN's new address (CoA).

Due to the nature of an IP-in-IP tunneling concept (CoA-HA address), Mobile IPv6 introduces extra header overhead. Mobile IP also increases the route-to-home delay latency. However, Mobile IPv6 with route optimization and other optimization extensions (e.g., Hierarchical MIPv6, Proxy MIPv6, Fast Handover of MIPv6, DSMIPv6, etc. [2, 9]) have been introduced to mitigate these problems.

Similar to other ID/Locator Split schemes, there are two levels of mapping: one from node name, Fully Qualified Domain Name (FQDN), to node ID and the other from the ID to its locators. Domain Name Server (DNS) is used to convert from FQDN to node ID and Home Agent (HA) is used for second level mapping. Note that the HA functions like a rendezvous server in other ID/Locator Split schemes.

Considering Mobile IPv6 as one of ID/Locator Split schemes, mobility is fully supported. However, traditional Mobile IP does not support multihoming. Recently multiple CoAs registrations and flow binding options [7, 8] were introduced to allow Mobile IPv6 to exercise this feature. Mobile IPv6 node can use multiple CoAs to communicate with both HA and its CNs. With this extension, Mobile IPv6 behaves similar to other ID/Locator Split schemes. However, neither Mobile IP nor the others consider the mechanism on what/how to make use of multiple interfaces underneath using link and path characteristics. We call these interface selection and flow distribution problems.

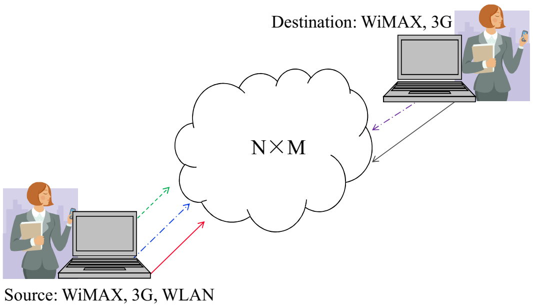

Fig. 1. Example of end-to-end multihoming (N×M = 3×2)

Each interface associated with per interface parameter: Throughput_Mbps (B_i), Charge_Cent/sec (C_i), and Power_ Joule/sec (P_i)
Turn on Power Charge (Assuming constant charge): P_c

Objective:

$$Min\{w_1 \times (t_1P_1 + t_2P_2 + ... + t_iP_i + i \times P_c) + w_2 \times (t_1C_1 + t_2C_2 + ... + t_iC_i) + w_3 \times (t_1 + t_2 + ... + t_i)$$

$$\sum_{i=1}^{N} w_i = 1, 1 \leq i \leq n$$

Constraints: $t_1B_1 + t_2B_2 + ... + t_iB_i \leq B\_total$

Optional Constraints: $t_1P_1 + t_2P_2 + ... + t_iP_i \leq P\_total$

$$t_1C_1 + t_2C_2 + ... + t_iC_i \leq C\_total$$

$$t_1 + t_2 + ... + t_i \leq T\_total$$

$$t_1, t_2, ..., t_i \geq 0$$

Fig. 2. Policy-based Minimization Formulation

III. INTERFACE SELECTION AND FLOW DISTRIBUTION

In general, the problem of selecting a networking interface has been investigated in the concept of "Always Best Connected [10]". The basic idea is to find the *best single active* interface given the interface characteristic and network constraints such as bandwidth, power consumption, access technology, and so on. This concept is purposely used for a hard handover purpose [11], that is, only one best active interface is allowed at any moment.

Now, let us consider Mobile IP. Recently a flow binding option [8] has been introduced to map a particular flow into a specific interface or CoA. Mobile IPv6 (i.e., a single home address used as node identity) can use this option to uniquely identify the flow. Note that this extension is based on the use of multiple CoAs registrations [7] that we described briefly earlier. To meet user requirements and QoS control parameters, a mechanism similar to policy-based model is required for Mobile IP.

With a single best active interface, there is a fundamental limitation. The multihoming feature cannot be fully utilized with only one interface. For example, suppose a user with a device with both 3G and WiMAX interfaces wants to maximize its throughput. Also, suppose the device is power-line operated and paid for by the flat rate fee; therefore, using two interfaces simultaneously will achieve twice as much throughput available for each application. Otherwise, a per-application or a flow distribution throughput will be limited by a per-flow distribution mapped to each interface.

Fig. 1 shows a simple configuration for the end-to-end multihoming. In this setup, there are three different interfaces at the source: WiMAX, 3G, and WLAN; and only two at the destination: WiMAX and 3G. Assuming there is a wired internet in between; there are 3×2 or 6 possible paths. The path characteristic, e.g., path throughput, congestion level, loss probability, end-to-end delay, and so on, may be different from one path to the others.

In addition, aside from achieving throughput aggregation, enabling multiple interface transmissions simultaneously allows Mobile IPv6 to support soft-handoff when two radio channels are used at the same time.

Therefore, in this paper we formalize a policy-based QoS and user requirement model incorporating constraints such as power consumption, air-time charges, and completion time. We consider the best N active interfaces for the purpose of throughput aggregation. However, we relax the problem if there is a high variation of a round trip time (RTT). The delay/RTT variation sensitive applications are distributed per flow, and for others we allow a single flow to be transmitted over N interfaces simultaneously.

Note that there have been several proposals to resolve the issue of throughput aggregation. These solutions may be classified by the aggregation layer such as session, transport, network, or link layer [2]. Each of these proposals has its pros/cons. For instance, the lower level modifications make upper layers unaware of the aggregation and multiple connections; however, they lack flow and QoS (application-based) information. The higher layer modifications do not need to change the lower protocol stack but there is no explicit mechanism to select a particular interface.

Consider Mobile IP. The modification occurs at the network layer. The change can only be done in the built-in Mobile IP agent. The upper layers do not need to be aware of this change. There are no requirements to modify other parts of the protocol stack. To achieve throughput aggregation, we propose a flow striping option for Mobile IPv6 to enhance the system throughput. Similar to [12], we apply a simple link scheduling, a Deficit Round Robin (DRR), to distribute a particular flow over N interfaces. This extension makes use of Mobile IPv6 flow binding option and multiple CoAs registrations [7, 8]. Notice that in Mobile IPv6, it is difficult to use multiple connections, especially in a scenario with a single home address and several connected CoAs. Note that for all solutions allowing multiple interface transmissions, protocol data unit re-ordering is required.

Furthermore, at the network layer, we introduce a connection manager that lies above the link layer or in the built-in Mobile IP agent. The link layer information such as channel conditions can help in making a proper selection decision. Similar to [13], we apply a TCP freeze technique to help mitigate the effect of disconnection operation caused by the TCP timing out in a Mobile IP environment.

IV. A POLICY-BASED QOS MODEL

In this section, we formulate our policy-based QoS model using linear programming. The target requirement is the expected bandwidth required for each application with several constraints such as total available power, user budget, and completion time.

Fig. 2 shows the minimization problem using linear programming. The objective function is to minimize the weighted power consumption (*P_total*), charges (*C_total*), and completion time (*T_total*). These parameters are normalized to per time unit (*t*). Users can arbitrarily set the weight according to their requirements and perspectives.

Notice that the throughput B_i used to meet the expected throughput *B_total* is the path throughput not the access bandwidth. The connection manager functions as a capacity estimator for different paths to CoAs. The resulting path throughout is used in the calculation. Also, users can always override the rules. For example, for delay/jitter sensitive applications, the users may choose the interface that meets their end-to-end jitter/delay expectations. Obviously, there is always a trade-off between user requirements and available resources.

A. Example

Consider a device equipped with two networking interfaces: WiMAX and 3G. The total battery power is 10 Joules. For each interface: capacity, usage charge, and power consumption are as follows: 1 Mbps, 1 cent/sec, 1 Joule/sec for WiMAX and for 3G, 0.5 Mbps, 3 cent/sec, and 0.01 Joule/sec. Suppose the user wants to send a 10Mb file.

If the user considers only the power consumption and there are no other constraints such as total budget or completion time, the user can set w_1 to *1* and other weights to *0*. Suppose $P_c = 0$, then the objective function here is $Min\ (t_1 + 0.01\times t_2)$, as a result with any well-known linear programming resolvers, the 3G interface is chosen for a 20-sec. transmission.

The user can also set the weights according to their requirements. For example, if w_1 and w_2 are set to 0.5 and suppose the completion time is required to be less than 8 sec. In this case, the objective function is $Min\ \{0.5(t_1 + 0.01\times t_2) + 0.5(t_1 + 3\times t_2)\}$. The WiMAX interface is chosen for 8 sec, and 3G for 4 sec.

V. CONNECTION MANAGER

In this section, we discuss the functionality of the connection manager. The connection manager is an extra module wrapped around the network layer or built-in the Mobile IP agent as shown in Fig. 3. The main idea of this manager is to distribute the flow among interfaces in an efficient way using the policy-based QoS model.

A. Flow Striping Option

Recently, a Mobile IP flow binding option has been suggested to distinguish a flow mapped to a particular CoA or interface. This allows the mobile node to exercise the multihoming feature of Mobile IP; however, this option uses only one active CoA. To truly benefit from the multihoming feature, we allow a flow to be striped over multiple (*N*) interfaces. We call this the flow striping option.

As shown in Figs. 4 and 5, the flow striping option (registration) is included in the binding update. The type field specifies the flow striping option. The length includes FID (flow identifier) and IPv6 CoAs and is specified in 8-octet units. FID is a 16-bit unsigned integer that identifies the flow binding. The set of *N* active interfaces or CoAs for this particular flow is specified in the IPv6 CoA field.

Any suitable distribution algorithm, e.g., weighted deficit round robin algorithm (WDRR) or a modified version of DRR so-called surplus round robin [12], can be used to distributed packets among various paths. Due to different RTTs along different paths, buffers are required in the receiver. The buffer size depends upon the difference between the maximum and minimum RTTs along any path. Obviously, there is a trade-off between received buffers vs. the total throughput gained from multiple interface transmissions.

To limit the variation of packet arrival times, the scheduler may select different size blocks or quantum along different paths. To mitigate out-of-order packets, a packet sequence number is used as one of the destination options to help the ordered delivery process at the receiving end.

Although per-packet based or per-bit based (fair queueing) distribution can achieve ideal load balancing and load sharing, and can make more efficient use of multihoming feature than per flow-based distribution, it may require more receiver buffers or may result in fragmentation overhead, especially if the variation of RTTs is high. As a result, the connection manager allows the user to override the rules. The connection manager allows only per flow distribution for those applications where ordered low-latency delivery is required, while it does flow striping for applications whose goal is to achieve high throughput or ordered delivery is not critical.

Again, the interface selection is based on the user decision. The connection manager only provides the information about interfaces and path characteristics (we will describe these in the next subsection) so the mobile user will finally select *N* interfaces for each particular flow.

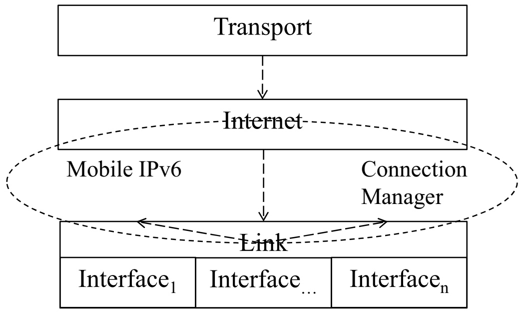

Fig. 3. Interface of Connection Manager

Type (1 byte)	Length (1 byte)	FID (2 bytes)
IPv6s (CoAs) . .		

Fig. 4. The flow striping mobility option (registration)

Type (1 byte)	Length (1 byte)	FID (2 bytes)
Interface/Path Characteristics e.g., buffer, timestamp, #byte count, access link technology		

Fig. 5. The flow striping mobility option (interface/path characteristic)

B. Interface/Path Characteristic Estimation

To help compute the proper weight for flow distribution or to provide useful information regarding the link characteristics, end-to-end parameters; such as path bandwidth, delay, congestion level, loss probability, end node buffer, etc. are required. Note that the connection manager can request the link layer characteristics such as modulation and coding schemes.

To estimate the path throughput, the connection manager does a heuristic path bandwidth estimation in that the number of bytes received is periodically counted. The achievable throughput is calculated by that number over time provided by a timestamp mechanism. Fig. 5 shows a flow striping mobility feedback option that indicates interface/path characteristics including receiver buffers used for the flow (group of CoAs), timestamp, and byte count.

If the link is symmetric, the results from the bandwidth estimation can be used, otherwise this information can be sent by piggybacking, or in a separate control channel to the other end. Timestamps can also be used to approximately estimate the end-to-end path delay. Note that the security considerations are out of scope of our paper; however, simple nonces and message authentication codes can be appended to the control message, if required.

Link congestion and/or loss indication, e.g., that obtained by the explicit congestion notification [14], can also be used in striping decisions.

C. *TCP Freeze Function*

Although Mobile IPv6 and its extensions can fully support the mobility of the end host when the IP address changes, it cannot support the mobility in a disruption operation scenario. Therefore, similar to [13] we make use of a TCP freeze option by sending the zero window advertisement to the transport layer to freeze the TCP from timing out, especially when the mobile nodes handover and/or dynamically change/add/delete groups of interfaces.

If the transport layer is unable to distinguish error losses from congestion, the connection manager can avoid congestion window reduction in case or error loss. In addition, link level recovery mechanisms such as (hybrid) automatic repeat request (H-ARQ), can be used to avoid error losses.

Since the connection manager is placed below the transport layer and the end host has link information from the other end, some useful transport mechanism ideas such as delaying an acknowledgement packet [15] built-in at the connection manager, can be implemented. This can reduce the effect of three duplicate acknowledgement packets by delaying the acknowledgement packets until H-ARQ mechanism takes effect.

VI. CONCLUSIONS

Next Generation Wireless Networks or NGWNs, will be an ubiquitous all-IP network. Users will be using devices with a variety of networking technologies and will be highly mobile. Some of the applications may need high throughput, e.g., video streaming. Mobile IPv6 and its optimization can be considered as a form of ID/Locator Split and are useful in achieving full mobility and providing multihoming support. Multiple CoAs registrations and flow binding options help Mobile IP support multihoming. To enhance the system throughput in such environments, in this paper we have introduced a flow striping option that allows a single flow to use *N* best interfaces simultaneously.

Moreover, we formalized the interface selection problem as a linear programming minimization problem using a policy-based QoS model based on user expectations and constraints. We relax the problem of per-packet distribution into per-application or per-flow distribution, in that, mobile users can override the rule. For example, RTT sensitive applications can use only per-flow distribution and allow a flow striping mechanism for others. Our formalization can achieve the throughput aggregation goal with the minimization of several constraints such as power consumption, transmission cost, and completion time.

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