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# Measuring Available Capacity for Mobile Networks with Multiple Wireless Interfaces

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## Abstract

This draft proposes an estimation scheme of available capacity for network mobility (NEMO) with the multi-interfaced mobile router (MMR). In the proposed scheme, mobile nodes (MNs) can get information on available capacity irrespective of the presence or absence of estimation functionality. Since the MMR with heterogeneous wireless network interfaces estimates available capacity on behalf of the MNs inside the mobile network, the proposed scheme does not require MNs to be involved in estimating available capacity. A new algorithm for available capacity estimation on MMR is developed to improve the estimation accuracy compared with the existing scheme. The developed algorithm defines three cases of the difference between the average output gap and the input gap, and then reflects fully them, which can reduce the detection error for the turning point and thus provide more accurate estimation than the existing algorithm. Then, MNs can get information on estimated available capacity from the MMR using L3 messages. Therefore, the proposed scheme can reduce burden and power consumption of MNs with limited resource and battery power since MNs do not estimates directly available capacity. In addition, the proposed scheme can reduce considerably traffic overhead over wireless links on multiple estimation paths since signaling messages and injected testing traffic are reduced.

## Status of this Memo

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## 1. Introduction

The available capacity of an end-to-end network path is its remaining capacity, that is, the amount of traffic that can be sent along the path without congesting it[1][2]. This available capacity between two hosts is an important network parameter for improving quality of service (QoS) in many distributed applications, such as the overlay construction of peer to peer system, optimization of resource utilization, optimization of dynamic server selection, socket buffer sizing, admission control, and congestion control. Therefore, recently, the area of end-to-end available capacity estimation has attracted considerable interest. As a result, several schemes for the available capacity estimation have been developed based on active measurements[3]-[5]. In active measurements, the

available capacity can be estimated by injecting probe traffic into the network, and then analyzing the observed effects of cross traffic on the probes. This kind of active measurement only requires access to the sender and receiver hosts.

Meanwhile, to deal with the mobility support of mobile networks, the Network Mobility (NEMO) techniques have been researched[6]. In the NEMO, the mobile router (MR) is capable of changing its point of attachment to the Internet without disrupting higher layer connections of attached devices. Therefore, mobile nodes (MNs) inside a mobile network are unaware of their network's mobility; however, they are provided with uninterrupted Internet access even when the network changes its attachment point to the Internet. This draft considers the mobile network with a multi-interfaced mobile router (MMR). In addition, to consider the heterogeneous wireless network environment [7][8], the MMR can be assumed to have multiple heterogeneous wireless network interfaces. Therefore, the MMR establishes simultaneously multiple paths to the Internet through external wireless interfaces such as wireless metropolitan area network (WMAN) and wireless wide area network (WWAN) with high mobility and wide coverage. However, due to capacity constraints of multi-path through external wireless interfaces, the MMR might require a capacity aggregation to get sufficient capacity for MNs' demanding inside a mobile network. The capacity aggregation requires generally several functions such as capacity estimation and packet distribution, etc. Among them, this draft focuses on the capacity estimation.

Generally, there can be often many MNs inside the mobile network with NEMO in heterogeneous wireless network environment. The MMR enables the multi-path communication outside the mobile network. Thus, MNs inside the mobile network can select the most appropriate communication path depending on the network environment and then communicate with corresponding hosts, such as the IPTV server, media streaming server, web server, FTP server, etc, via the MMR. If MNs want to understand the condition of multiple communication paths, they will estimates directly available capacity for each path. Therefore, all MNs inside the mobile network are required to be involved in estimating available capacity and thus have to implement estimation functionality, which can be somewhat burdensome and power consumptive for MNs with limited resource and battery power. In addition, there can be the number of estimation signaling messages and injected testing traffic as shown in active measurement approaches[3], which can cause considerable traffic overhead over wireless links on estimation paths.

Therefore, this draft proposes an available capacity estimation mobile networks. In the proposed scheme, when MNs inside the mobile network want to understand the condition of multiple communication paths outside the mobile network, they can get available capacity irrespective of the presence or absence of estimation functionality. That is, the proposed scheme does not require the MN to be involved in estimating available capacity. Instead, the MMR estimates available capacity on behalf of the MNs inside the mobile network. The proposed available capacity estimation scheme requires an estimation algorithm. Thus, in this draft, a new algorithm is proposed based on the IGI/PTR scheme[3][4] to reduce the detection error of the turning point and enhance the accuracy of the available capacity estimation. The proposed algorithm reflects fully three cases, while the existing IGI/PTR algorithm reflected only two cases. Since three cases are handled respectively by appropriate corresponding manners, the proposed algorithm can be expected to reduce the detection error for the turning point. Therefore, the end-to-end available capacity can be estimated more accurate than existing algorithm.

## 2. Technical Background

### 2.1 End-to-End Path for Mobile Network

This draft considers the mobile network in heterogeneous wireless networks. The MR is capable of changing its point of attachment to the mobile network, moving from one link to another link. To consider heterogeneous wireless networks, the MR is assumed to be multi-homing and thus called the multi-interfaced mobile router (MMR). The MMR has heterogeneous multiple network interfaces which are categorized by internal and external wireless interfaces. With the consideration of coverage and capacity, internal wireless interfaces attached to MNs inside the mobile network would be WLAN and external wireless interfaces attached to external base stations would be WMAN and WWAN. Therefore, the MMR enables the multi-path communication outside the mobile network through these heterogeneous wireless interfaces. Meanwhile, MNs inside the mobile network are assumed to have single wireless interface or heterogeneous multiple wireless interfaces. Corresponding hosts (CHs) can be the IPTV server, media streaming server, web server, FTP server, etc. MNs inside the mobile network can communicate with CHs on multiple paths via the MMR.

The end-to-end multi-path from MNs inside the mobile network to CHs outside the mobile network via the MMR consists of following three links. Inside the mobile network, there is a link between MN and MMR. The WLAN will be generally adopted as an air technology due to high transmission speed and moderate coverage. Thus, MNs with WLAN interface can communicate via the MMR with internal WLAN interface inside the mobile network. Outside the mobile network, there is a link between MMR and external BSs. The WMAN and WWAN will be generally adopted as an air technology due to wide coverage. Thus, the MMR with external WMAN and WWAN interfaces can communicate via corresponding base stations (BSs). However, in this wireless link, it is difficult to expect higher transmission speed than that of the wireless link between MNs and MMR using WLAN. The link between external BSs and CHs consists generally of routers with high processing speed and wired networks with high transmission speed.

### 2.2 Existing Available Capacity Estimation : IGI/PTR

The IGI(Initial Gap Increasing)/PTR(Packet Transmission Rate) algorithm [3][4] was proposed for the available capacity estimation and shown to be much faster than existing algorithms with similar estimation accuracy but with shorter estimation latency. This algorithm is based on a single-hop gap model that captures the relationship between the competing traffic and the probing packet train. As a sequence of probing packet trains from the source travel through the network, packets belonging to the competing traffic may be inserted between them, thus increasing the gap at the destination. As a result, the average output gap value at the destination may be a function of the competing traffic rate, making it possible to estimate the amount of competing traffic. That is, the average output gap can be used to determine the competing traffic capacity and hence the available capacity on the end-to-end path assuming that the bottleneck link capacity along the end-to-end path is known. At some point, the average output gap equals the average input gap as gaps in a probing packet train increase. This point is called the "turning point". At the turning point, the input gap value for which the average output gap is equal to the input gap is the right value to use for estimating the available capacity. However, there are some issues in the existing IGI/PTR algorithm. After performing the estimation, three cases are defined according to the difference between the average output gap and the average input gap. These three cases mean that the average output gap at the destination is (a) larger than, (b) equal to, (c) less than the average input gap at the source. These three cases have respectively different relationship between the average rate of the probing packet train and the available capacity. However, the existing algorithm did not reflect fully these three cases in order to reduce the estimation latency. That is, both (b) and (c) cases are handled in the same way, which can introduce the detection error for the turning point since (b) and (c) cases are absolutely different. Therefore, the available capacity can be estimated inaccurately although the estimation latency can be reduced.

## 3. Available Capacity Estimation Scheme

If MNs inside the mobile network measure directly IP performance metrics, they are required to be involved in the measurement procedure and thus have to implement measurement functionality, which can be somewhat burdensome and power consumptive for MNs with limited resource and battery power. In addition, there can be the number of measurement signaling messages and injected testing traffic, which can cause considerable traffic overhead over the wireless links, such as link between MN and MMR, and link between MMR and external BS, on measurement paths. In addition, as mentioned previous section, the wireless link between MMR and external BS is likely to be overloaded network link, that is, "bottleneck link". Moreover, if there are many mobile networks connected to external BS, this link is likely to be "tight link". This means that IP performance metrics of the end-to-end multi-path might be mostly influenced by the wireless link between MMR and external BS.

With the consideration of these problems, a measurement scheme of IP performance metrics is proposed for the mobile network in heterogeneous wireless networks. In the proposed scheme, when MNs inside the mobile network want to understand the condition of multiple communication paths outside the mobile network, they can get IP performance metrics irrespective of the presence or absence of measurement functionality. Since the MMR with heterogeneous wireless interfaces measures IP performance metrics on behalf of the MNs inside the mobile network, the proposed scheme does not require MNs to be involved in measuring IP performance metrics.

## 3.1 Component

Main components on the end-to-end measurement path consist of MNs, MMR, and measurement server. MNs inside the mobile network are assumed to have a single wireless interface or heterogeneous multiple wireless interfaces. When MNs want to get IP performance metrics to understand the condition of multiple communication paths, they can request to the MMR using the L3 message. Also, MNs can get IP performance metrics that the MMR provides periodically. The MMR measures IP performance metrics on behalf of the MNs inside the mobile network. Since the MMR have heterogeneous external wireless interfaces such as WMAN and WWAN, the MMR enables the multi-path communication outside the mobile network and thus can measure IP performance metrics for all paths through these heterogeneous external wireless interfaces. The measurement server is a host that receives testing traffic, calculates performance statistics, and response results of IP performance metrics to the MMR.

## 3.2 Algorithm for Available Capacity Estimation

A new scheme for available capacity estimation is proposed to improve the estimation accuracy compared with the existing scheme. As mentioned before, since (b) and (c) cases handled in the same way are absolutely different, they should be handled by respectively.

In this section, a new algorithm for available capacity estimation is developed to improve the estimation accuracy compared with the existing algorithm. As mentioned in Section 2, since cases (b) and (c) handled in the same way are absolutely different, they should be handled by respectively. Following parameters are defined:

- A_bw : Available capacity.
- B_bw : Bottleneck link capacity.
- C_bw : Competing traffic capacity.
- Gap_out : Average output gap.
- Gap_in  : Average Input gap.
- Delta : Equality boundary.
- R_pkt: Average rate of the packet train.

The end-to-end available capacity is defined as the difference between the bottleneck link capacity along an end-to-end path and the competing traffic. The bottleneck link capacity in the path determines the end-to-end capacity which is the maximum IP layer rate that the path can transfer from source to destination. In other words, the capacity of a path establishes an upper bound on the IP layer throughput that a user can expect to get from that path. There are diverse measurement schemes for the bottleneck link capacity. Therefore, the bottleneck link capacity can measured from one of existing schemes.

There are several important probing parameters such as probing packet size, number of probing packet in packet train, and input gap to get correct measurement. Among them, input gap in a probing packet train is the most important parameter to control for accurate available capacity estimation. The source sends a sequence of probing packet trains with adjusting input gap. The difference between the average output gap and the input gap is observed for each train. Then, the turning point is detected for estimating the available capacity.

After performing a measurement, three cases are defined according to the difference between the average output gap Gap_out$ and the input gap Gap_in. Three cases are called 'Larger Than (LT)', 'Equal To (EQ)', 'Smaller Than (ST)' cases which have respectively different relationship between the average rate of the probing packet train and the available capacity. These three cases are handled respectively. As shown in three cases, the proposed algorithm handles 'EQ' and 'ST' cases respectively while the existing algorithm handles them in the same way.

| Cases | Condition | Meanging |
|---|---|---|
| LT | Gap_out > Gap_in + Delta/2 | R_pkt > A_bw |
| EQ | \|Gap_out - Gap_in\| < Delta | R_pkt = A_bw |
| ST | Gap_out < Gap_in + Delta/2 | R_pkt < A_bw |

(A) 'LT' Operation

The estimation is repeated with the increased input gap. After then, three cases observed once again. For each case, the estimation is repeated with adjusting input gap as follows:

- LT : increased input gap
- EQ : same input gap as previous estimation
- ST : decreased input gap

In the existing algorithm, the estimation is repeated with the same input gap as previous estimation for 'ST' case.

(B) 'EQ' Operation

The estimation is repeated with the same input gap as previous estimation. After then, three cases are observed once again and then handled respectively as follows:

- LT : estimation with increased input gap
- EQ : estimation finished (turning point detected)
- ST : estimation with decreased input gap

In the existing algorithm, the estimation is finished for 'ST' case.

(C) 'ST' Operation

The estimation is repeated with the decreased input gap. In the existing algorithm, the estimation is repeated with the same input gap in this case. After then, three cases are observed once again and then handled respectively as follows:

- LT : estimation with increased input gap
- EQ : estimation finished (turning point detected)
- ST : estimation with decreased input gap

In the existing algorithm, the estimation is finished for 'ST' case.

When the turning point is detected, the measurement is finished and then the end-to-end available capacity can be estimated as follows. The end-to-end available capacity is obtained by subtracting the competing traffic capacity from the bottleneck link capacity as follows:

$$A_{bw} = B_{bw} - C_{bw}$$

As mentioned before, the bottleneck link capacity can be measured from one of existing schemes. Then, the competing traffic capacity can be computed using the average output gap and the input gap at the turning point, and the bottleneck link capacity.

### 3.3 Interaction between MMR and MNs

When MNs want to get IP performance metrics from the MMR to understand the condition of multiple communication paths, following two methods can be available:

- Unsolicited Reqeust and Response : Irrespective of the request of MNs, the MMR broadcasts periodically measured IP performances metrics to MNs inside the mobile network.
- Solicited Request and Response : A specific MN requests and then the MMR unicasts measured IP performance metrics to the corresponding MN.

Request and Response messages can be defined by the Internet Control Message Protocol (ICMP) message format in [10]. For example, for unsolicited request and response, the unsolicited router advertisement (RA) message format in [10] can be reused by the modification of type field. For solicited request and response, route solicitation (RS) and router advertisement (RA) message formats in [10] can be reused by the modification of type field. Using obtained IP performance metrics, MNs can understand the condition of multiple communication paths for heterogeneous multiple wireless interfaces. Then, MNs may want to select the most appropriate path per communication type. If the condition of all communication paths is unfavorable, MNs with heterogeneous multiple wireless interfaces can connect to the corresponding BS directly, not via the MMR.

## 4. IANA Considerations

This document has no IANA actions.

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