이기종 무선망에서의 TCP 성능 기반 수직적 핸드오프 결정 방안

(TCP Throughput Effective Vertical Handoff Decision Scheme for Heterogeneous Wireless Networks)

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요 약 수직적 핸드오프는 전송대역, 전송지연시간, 전파영역이 다양한 무선망들이 중첩되어 있는 환경에서의 새로운 형식의 핸드오프이다. 수직적 핸드오프를 통하여, 무선 단말은 최적의 전송대역을 제공하는 무선망을 선택할 수 있다. 그러나 TCP 전송률 관점에서는 이러한 수직적 핸드오프가 항상 향상된 성능을 제공하는 것은 아니며, 낮은 전송대역을 제공하는 무선망에 머무르는 것이, 높은 전송대역을 선택하여 이동하는 것보다 더 좋은 성능을 보이기도 한다. 본 논문에서는, 수직적 핸드오프 환경에서의 TCP 전송률을 예측하며, 예측된 TCP 전송률에 기반하여 최적의 TCP 전송률을 제공할 수 있는 수직적 핸드오프 결정 방안을 제시하고자 한다. 시뮬레이션 연구를 통하여 검증하였다.

키워드 : 수직적 핸드오프 결정, TCP 전송률, 이기종 무선망

Abstract Vertical handoff is a new type of handoff in wireless networks. It is issued when a mobile node moves over overlapping wireless networks with each proving a different access bandwidth, transmission latency, and coverage. By issuing the vertical handoff, the mobile node can obtain better network bandwidth. In the sense of TCP throughput, however, the vertical handoff does not always produce positive performance gain, so sometimes it is better for the mobile node to stay at lower bandwidth providing network rather than to select and move to higher bandwidth providing network. In this paper, we analyze TCP throughput for vertical handoff, and propose a new handoff decision scheme which can estimate TCP throughput at the moment of vertical handoff. Based on the estimation, a mobile node can decide to issue vertical handoff to produce better TCP throughput, and we verify the results by simulations.

Key words : Vertical handoff decision, TCP throughput, Heterogeneous wireless networks

1. Introduction

In coming future wireless networks, multiple different types of wireless networks are expected to be overlaid, with each providing varying access bandwidth and coverage level. A mobile node in a vehicle or a human-hand moves over two or more different types of the wireless networks, and we refer to such a procedure that handles handoff between them as vertical handoff. Specifically, we call it downward vertical handoff when the mobile node moves from a lower bandwidth providing network to a higher, and upward vertical handoff when vice versa [1,2].

As shown in Fig. 1, a mobile node in a vehicle moves over two different types of wireless networks successively. A cellular network has lower bandwidth and larger coverage than a WLAN

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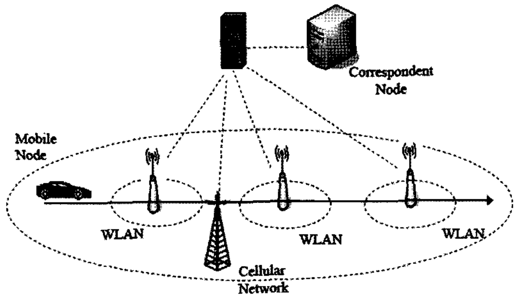


Fig. 1 Vertical Handoff: A MN(Mobile Node) moves over multiple wireless networks with communicating with CN(Correspondent Node). Cellular network has large coverage and low bandwidth, and WLAN has small coverage and high bandwidth

(Wireless LAN). Downward vertical handoff occurs when the mobile node moves into WLAN, and upward vertical handoff when out of it. While upward vertical handoff must be issued to maintain the connection with CN(Correspondent Node), downward vertical handoff is not a mandatory but an optional procedure because the coverage of WLAN is included in cellular network.

It is quite advantageous that a mobile node issues downward vertical handoff and gets higher bandwidth. The longer as the mobile node stays at WLAN, the higher as the throughput it can achieve. In the sense of TCP throughput, however, vertical handoff does not always produce positive throughput gain due to the drastic changes of bandwidth and latency which produce a bunch of packet reordering, link underutilization, packet overflows, and spurious timeout [3-8]. So, it sometimes would be better to stay at cellular network rather than to issue downward vertical handoff to move to WLAN.

In [9], most of traffic measured at a backbone network is TCP traffic, and 40% of the amount of data are carried by streams with lifetime more than 1000 second. Consequently, serious considerations should be given toward long-lived TCP because the current data traffic characteristics could continue in future networks. However, previous vertical handoff decision studies do not give much considerations on TCP yet. Most of the studies introduced vertical handoff schemes, and proposed ideas to select the best network to meet user's preference or optimal performance of network layer or below.

[10] and [11] proposed a vertical handoff decision for the best selection to meet or optimize QoS requirements, performance metric by a policy, and user's preferences of network layer. [12] proposed a cost function that can produce optimized use of network resource from the variety of users- and network-valued metrics. [13] and [14] proposed a vertical handoff decision to reflect users preference to network layer resources and battery consumption, respectively.

In the context of TCP consideration, [15] mentioned and proposed a vertical handoff decision about optimizing TCP performance. They proposed to build a look-up-table of TCP connection time, mobile speed, and overall handoff performance. Handoff is initiated only if the overall performance is estimated positive. However, they have to prepare the look-up-table in advance for all possible cases, and they also need GPS(Global Positioning System) hardware to measure the speed of mobile node. They do not consider other parameters like bandwidth and RTT(Round Trip Time) which are important factors to TCP performance.

In this paper, we analyze the performance of TCP for vertical handoff in wireless networks, and propose an elegant way of vertical handoff decision optimizing TCP throughput. Our proposed handoff decision can estimate TCP throughput without any pre-built look-up-table and any additional hardware. It also takes into account bandwidth and RTT in the estimation.

2. TCP Throughput Estimation for Vertical Handoff

Based on the analysis of TCP behavior, we can estimate positive and negative gain of TCP throughput for vertical handoff. Our estimation assumes that different types of wireless networks are overlaid as shown in Fig. 1. Our proposed handoff decision scheme issues downward vertical handoff when the positive gain of TCP performance is larger than the negative gain. On the other hand, it does not issue the handoff.

2.1 TCP Considerations

Downward vertical handoff to WLAN gives higher bandwidth and lower link latency, but TCP has to experience handoff latency, RTO expiration, and a bunch of duplicate packets. In the sense of TCP throughput, negative and positive gain are co-existed on downward vertical handoff. Higher bandwidth and lower link latency are the positive gain, but the sudden change of network conditions and handoff latency are the negative gain.

For different handoff methods such as soft handoff and hard handoff, we have to consider TCP performance differently. In case of hard handoff method, TCP has to experience vertical handoff latency on both of downward and upward vertical handoff, denoted as T_{down} and T_{up} respectively in Fig. 2. [4] measured T_{down} as 7 seconds and T_{up} as 4 seconds respectively. The handoff also forces TCP to expire RTO multiple times successively, and then SSTHRESHOLD (Slow-Start THRESHOLD) comes to set by almost 1. It makes TCP start with congestion avoidance mode from CWND (Congestion WiNDow) 1 after the timeout. So, the time to get to newly assigned high bandwidth becomes very long because TCP has to increase just one CWND after one RTT [7]. We denote this period as T_{adapt} in Fig. 2.

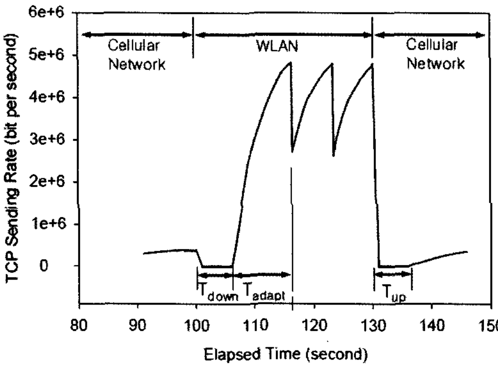


Fig. 2 TCP Throughput Curves: A WLAN is overlaid by a cellular network. The WLAN provides 5Mbps, and the cellular network provides 384Kbps. A mobile node passes through the cellular network first, then passes through the WLAN, and finally gets to the cellular network again. The mobile node meets a downward vertical handoff at 100 second, and stays at the WLAN for 30 seconds, and meets upward vertical handoff at 130 second. Hard handoff method is used for this simulation

In case of soft handoff method, a bunch of packets are received with reordered on downward vertical handoff, and this forces the received packets to be dropped because the reordered packets are considered as duplicate packets [4,5].

This period comes under T_{down}. Among TCPs, TCP SACK shows the best performance while other TCPs suffer seriously from the bunch of packet reordered because congestion recovery mode takes very long time in retransmitting all the reordered packets [16]. On upward vertical handoff, RTO expirations occur due to suddenly prolonged link latency [7,8]. Then, TCP has to wait for timeout to be expired without transmitting any packet, and this comes under T_{up}.

To verify the overall TCP throughput, we used ns-2(network simulator 2) simulations with the same scenario used in Fig. 2. We set 7 seconds and 4 seconds for downward and upward vertical handoff latencies, respectively as mentioned in [4]. TCP SACK runs file transfer for this simulations. The results are shown in Fig. 3.

Flow 0 does not issue downward vertical handoff even though it could do. Others issue downward

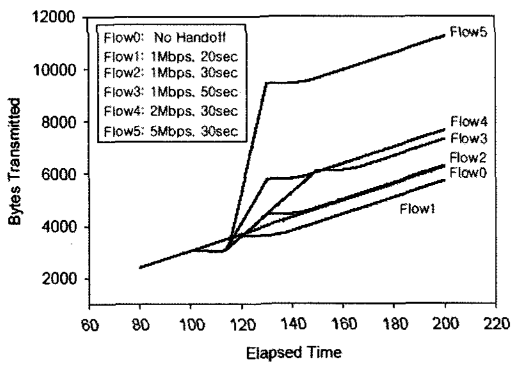


Fig. 3. The Amount of Bytes TCP Transmits: Flow0 always stays at cellular network without downward vertical handoff, and others issue downward vertical handoff to WLAN. Simulations have the same network conditions with those of Fig. 2

vertical handoff at 100 second. After the downward vertical handoff, 5 TCP flows have each different durations staying at WLAN and this is supposed to represent different speeds of a mobile node. Then they have to issue upward vertical handoff to cellular network when leaving the WLAN. In staying at the WLAN, they get assigned different bandwidths because access point in a WLAN assigns different bandwidths to a newly arrived mobile node depending on the distance between the mobile node and the access point, and network conditions.

While Flow2, Flow3, Flow4, and Flow5 achieved better performance than Flow0, Flow1 got worse performance even though it issued downward vertical handoff and is provided higher bandwidth and lower link latency. This means that not all downward vertical handoffs to WLAN do not give better TCP throughput than just staying at cellular network. For the case of Flow 1, staying at cellular network could produce better performance than issuing downward vertical handoff to WLAN.

2.2 TCP Throughput Estimation

We denote G_w as the amount of data to be received while staying at a WLAN after downward vertical handoff, and G_{wo} as the amount of data to be received while staying at cellular network during exactly the same duration a mobile node could stay at WLAN if it would issue downward vertical handoff. If G_w is larger than G_{wo}, then it is better to issue downward vertical handoff, otherwise, it is better not to issue it.

G_{wo} can be simply derived as follows. Because TCP should be in congestion avoidance mode, CWND varies from the half of the previous top to the top repeatedly. The sending rate, $R_{Cellular}$, also varies as CWND varies, so the average sending rate is $0.75 \times R_{Cellular}$ where $R_{Cellular}$ is the bandwidth provided by cellular network.

$$G_{wo} = 0.75 \times R_{cellular} \times (T_{WLAN} + T_{UP}).$$

T_{WLAN} is the duration a mobile node could stay at WLAN if the mobile node would issues downward vertical handoff, and it includes T_{down}. T_{up} and T_{down} are the period mentioned in Fig. 2.

G_w can be derived as two phases. The first phase includes the period denoted as T_{adapt} shown in Fig. 2. In this period, TCP linearly increases CWND from 0 to top which means the available bandwidth of WLAN. The second phase includes the period during when CWND varies between the half of the previous top and the top repeatedly as shown in Fig. 2.

$$G_w = \sum_{i=1}^{N_{adapt}} i \times MSS \times 8 + 0.75 \times R_{WLAN} \times T_{active}.$$

The first term, $\sum_{i=1}^{N_{adapt}} i \times MSS \times 8$, means the data transmitted during T_{adapt} and the second term means TCP congestion avoidance mode after T_{adapt}. N_{adapt} is the number of stalling to receive ACK segments during T_{adapt}. During T_{adapt}, CWND increases linearly because SSTHRESHOLD should be set by 1 due to successive RTO expirations by hard handoff or a bunch of duplicate ACKs by soft handoff. R_{WLAN} is the bandwidth provided by WLAN. T_{active} is the duration a mobile node can transmit data at WLAN after downward vertical handoff. N_{adapt} and T_{active} can be derived as follows.

$$N_{adapt} = \max\{i | RTT + MSS/R - (i-1) \times MSS/R \geq 0\}.$$

The time to occupy the available bandwidth is $(i-1) \times MSS/R$, where i is an integer, and MSS/R is the time for sending a segment. To use up the available bandwidth completely, the time should be equal to or exceed $RTT + S/R$. If it exceeds $RTT + MSS/R$, that means the sending rate exceeds the available bandwidth. N_{adapt} becomes as follows finally.

$$N_{adapt} = 2 + RTT \times R/MSS$$

$$\approx RTT \times R/MSS.$$

T_{active} is the time during which a mobile node can send data at WLAN. T_{WLAN} is the whole time of staying at WLAN, then,

$$T_{active} = T_{WLAN} - T_{down}.$$

To issue handoff to have optimized TCP performance, the handoff will be issued when G_w is bigger than G_{wo}. Table 1 shows the results of TCP throughput estimation for the simulations shown in Fig. 3. The proposed TCP throughput estimation can decide accurately whether the downward vertical handoff is issued or not for these examples. Flow1 is recommended not to issue downward vertical handoff, and that is matched well with the results of the simulations of Fig. 3.

Table 1. Handoff Decision based on Proposed Estimation; Flow1 is estimated not to issue downward vertical handoff while others are estimated to issue the handoff. The estimations have the same results of the simulations

	Bandwidth	Duration	G_w	G_{wo}	Preferred Decision
Flow5	5.5Mbps	30sec	67.51M	11.23M	Issue
Flow4	2Mbps	30sec	27.00M	11.23M	Issue
Flow3	1Mbps	50sec	28.50M	16.99M	Issue
Flow2	1Mbps	30sec	13.50M	11.23M	Issue
Flow1	1Mbps	20sec	6.00M	8.35M	Not Issue

3. Proposed Handoff Decision

In this section, we propose a new vertical handoff decision scheme based on our proposed TCP throughput estimation. To estimate TCP throughput at the moment of downward vertical handoff, we need to know the parameters used in the estimation. The way to know them depends on what types the accessing networks are and what protocols they use.

We consider two network types, a WLAN and a cellular network. WLAN has small coverage but high bandwidth while cellular network has large coverage but low bandwidth. Multiple WLANs can be overlaid by a cellular network, and the move from WLAN to cellular network is an upward vertical handoff, and the opposite directive move is a downward vertical handoff. We assume that hard handoff method is used.

3.1 Proposed Handoff Decision

To estimate G_w and G_{wo}, we need to know R(Bandwidth), MSS, RTT, T_{down}, T_{up}, and T_{WLAN} at the moment of or before downward vertical handoff. The way to know them are introduced as follows.

- M_{SS} : It can be read from a pre-defined value in a special purpose file in a system.
- R (Bandwidth) : It depends on the version of 802.11, the antennas on each device, the distance between an access point and a mobile node and how many other nodes are requesting bandwidth [17]. In the header of PLCP(Physical Layer Convergence Protocol) which is a part of wireless physical layer, SIGNAL field indicates how fast the payload will be transmitted such like 1,2,5.5, or 11Mbps [18].
- RTT : An accumulated average of RTT is measured and kept implicitly with TCP protocol [19].
- T_{down} and T_{up} : They are the periods during which TCP cannot send segments. In hard handoff, this comes from the handoff latency which consist of detect, registration, and binding update [4]. In case of soft handoff, this comes from packet drops due to successive packet reordering, and RTO expirations due to suddenly prolonged link latency [7,8]. The two durations are measured at the first visit to WLAN and used for our estimation for subsequent visits.
- T_{WLAN} : The duration between the time the mobile node detects WLAN and the time it loses the access to WLAN. This is measured at the first visit to WLAN and used for our estimation for next subsequent visits.

Among the parameters, MSS can be known easily just by reading a file in advance. R can be known at the moment of vertical handoff decision by reading the header of physical layer protocol. But the other parameters such T_{down}, T_{up}, RTT, and T_{WLAN} are not available at the moment of vertical handoff. To get the variables, we propose to force a mobile node to issue downward vertical handoff to WLAN firstly to measure them. Including this policy, we proposed vertical handoff decision scheme as follows.

Algorithm 1. The Proposed Vertical Handoff Decision

For the first visit to WLAN
- issue downward vertical handoff
- measures T_{up}, T_{down}, and T_{WLAN}
- extract $sRTT$ in TCP variables and keep as RTT

For the second or subsequent visits to WLAN
- retrieve bandwidth information, R
- calculate G_{wo} and G_w and compare them
- if G_w is bigger than G_{wo}
  - then issue Downward Vertical Handoff
  - else does not issue Downward Vertical Handoff
- update T_{WLAN}, T_{down}, T_{up}, and RTT (averages are maintained)

The proposed decision scheme will be initiated at the edge of WLAN where a mobile node will make a decision of handoff to WLAN. An WLAN AP

(Access Point) transmits a steady stream of beacon frames. Beacons are used to advertise the AP's capabilities, including the AP's Service Set Identifier (SSID), supported data rates, use of short preambles, channel agility, modulation options, privacy requirements, and authentication and cipher suites. Meanwhile, the mobile node receives the beacon frames and transmits IEEE 802.11 frames as presence signals by radiating Radio Frequency(RF) energy at a given strength, referred to as Equivalent Isotropically Radiated Power (EIRP). Authentication via IEEE 802.1x and IEEE 802.11 association between the mobile node and the WLAN AP starts. An 802.11 association only provides data link (Layer 2) connectivity. The data link connectivity enables the mobile node to IP-communicate. It means Mobile-IP can operate via dual interfaces(WLAN or cellular network interface) [20,22]. At the time, handoff is ready to take place according to the proposed decision scheme. The information used for the proposed TCP throughput estimation will be updated and kept in the mobile node for the next use.

3.2 Prediction Error and Target Applications

The proposed vertical handoff decision predicts the throughput which a mobile node can obtain in staying at WLAN. The prediction error between the prediction and the real value, denoted by e, can be represented as follows.

$$e = |G_w - G'_w|.$$

G'_w is real throughput a mobile node will obtain. The major parameter to make e non-zero is T_{WLAN}. To predict T_{WLAN} with the previously accumulated average value before vertical handoff can produce non-zero e. So, in the situation a mobile node moves in very randomly varied speed, the proposed vertical handoff decision will not work well, otherwise, it is expected to work well, however. The situation that the speed of a mobile node does not change dramatically is preferred for the proposed vertical handoff decision.

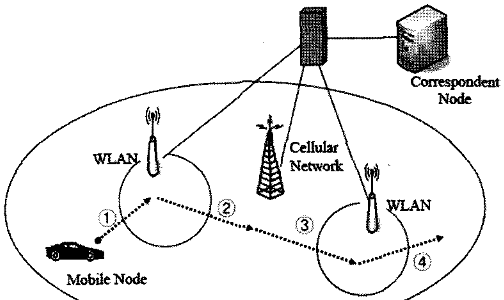
The popular Internet services which have to run long-lived TCP like peer-to-peer file sharing, multimedia e-mail, and ftp could continue to be popular in future network too. A mobile node moving in a sustainable random speed and running long-live TCP can achieve great performance gain by the proposed vertical handoff decision scheme.

4. Verifications by Simulations

Our proposed vertical handoff decision is compared with RSS(Radio Signal Strength) scheme that uses radio signal strength as the indicator of vertical handoff decision. Using RSS for handoff indicator is used in many research works [20,21], and that detect and decide handoff by the strength of radio signal. Our proposed handoff decision scheme is also based on RSS to detect handoff, but the decision is depended on our proposed TCP throughput estimation. The metric to consider for the performance of the proposed scheme and the RSS scheme is the degree of handoff decision accuracy about TCP throughput and the amount of data transferred.

4.1 Simulation Environments

Fig. 4 shows the topology of nodes and the scenario used in the simulations in this section. We suppose the wireless link of cellular network provides 600 ms latency and 384 Kbps bandwidth, and the wireless link of WLAN provides 60 ms latency and 4 different (1Mbps, 2Mbps, 5.5Mbps, 11Mbps) bandwidths. All other wired links are supposed to be 10 ms latency and 100 Mbps bandwidth. The maximum segment size is 1460 bytes. In the environment, we run FTP(File Transfer Protocol), which basically works on TCP. The traffic of FTP is continuously transferred from source node to



① : The proposed scheme and RSS issue downward vertical handoff.
③ : The proposed scheme makes a decision based on the estimated TCP throughput while RSS must issue downward vertical handoff.

Fig. 4 Simulation Topology and Scenario

destination node in a given duration. Its rate will fluctuate due to TCP congestion control. At the starting time, the amount traffic will go up exponentially by slow start of TCP, and will go and down repeatedly due to congestion avoidance mode of TCP. The simulations are done with ns-2.

In the results shown in Fig. 5 and Fig. 6, X axis is the duration staying at the first WLAN. If the duration of subsequently staying at WLAN is the same with the first duration, the proposed vertical handoff decision scheme would produce accurate decisions with very high probability. However, in real environment, the duration depending on the speed of a mobile node varies randomly. To emulate this, the duration of subsequently staying at WLAN is randomly changed by 10% by uniform distribution.

We do 100 trials and record the percentage of the correct handoff decision at Y axis. The correct

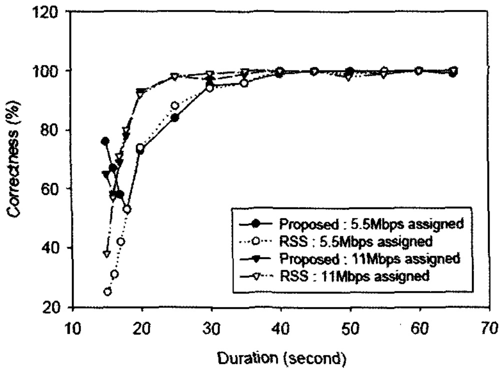


Fig. 5 Handoff Decision Correctness for 11Mbps and 5.5Mbps assigned Cases

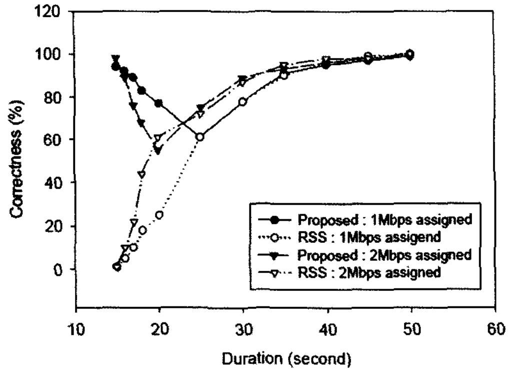


Fig. 6 Handoff Decision Correctness for 2Mbps and 1Mbps assigned Cases

handoff decision means that the decision produces better TCP throughput than the throughput obtained by the other way. RTT is also randomly changed by 10% by uniform distribution.

4.2 Results and Discussions

In Fig. 5, a mobile node is assigned with 5.5Mbps and 11Mbps. The correctness of RSS scheme gets better as the duration gets longer at X axis. In shortly staying before 15 seconds and 18 seconds for 11Mbps and 5.5Mbps respectively, the correctness is less than 50%, which means the decision made by RSS scheme is wrong actually. The negative performance gain for shortly staying could be larger than the positive performance gain, but RSS scheme forces a mobile node to issue downward vertical handoff. On the other hand, the proposed scheme does not always issue downward vertical handoff but depends on the proposed estimation. So, it can produce better correctness for shortly staying period. The proposed scheme has better correctness only about less duration than 15 seconds and 18 seconds for 11Mbps and 5.5Mbps, respectively. That is because 11Mbps and 5.5Mbps are large bandwidth enough that positive performance gain could be larger than negative performance gain when longer staying than 15 seconds and 18 seconds for 11Mbps and 5.5Mbps cases, respectively.

In Fig. 6, a mobile node is assigned with 1Mbps and 2Mbps. The proposed decision scheme decides not to issue downward vertical handoff by 20 seconds and 25 seconds for 1Mbps and 2Mbps, respectively while RSS scheme issues the downward vertical handoff always. The decision made by the proposed scheme has much higher correctness than RSS scheme, because the positive performance gain for small bandwidth is not much big enough to offset the negative performance gain for short duration.

From the results of Fig. 5 and Fig. 6, we can figure out that the proposed scheme shows better correctness for shortly staying at WLAN with lower bandwidth assigned. That is because the proposed scheme can decide not to issue downward vertical handoff when positive performance gain acquired by high bandwidth and low link latency is expected

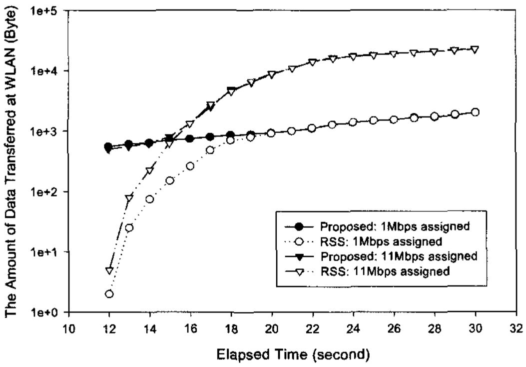


Fig. 7 The amount of data transferred for the cases of 1Mbps and 11Mbps assigned

lower than negative performance gain caused to handoff latency, RTO expirations, and packet reordering. Our proposed handoff decision can be applied well for the mobile node which is assigned low bandwidth and moves fast through multiple WLANs overlaid by a cellular network.

In Fig. 7, a mobile node is assigned with 1Mbps and 11Mbps. For the 1Mbps case, the amount of data transferred by the proposed decision scheme is more than by RSS scheme before 20 second, and there is no difference between the two schemes after 20 second. Before 20 second, the proposed decision scheme is likely to decide for staying at cellular network rather than for moving to WLAN, which improves the performance of TCP data transfer shown in Fig. 7. For the 11Mbps case, the proposed scheme achieves the performance gain before 15 second. The proposed scheme is likely to decide for moving to WLAN and there becomes no difference between two schemes after 15 second. Before 20 and 15 second, the proposed handoff decision scheme transmits more data than RSS.

5. Conclusions

In heterogeneous wireless networks, the vertical handoff makes the performance of TCP degraded due to sudden changes of available bandwidth and latency in end-to-end path. In this paper, we proposed a new handoff decision scheme, which estimates TCP throughput for vertical handoff. It will issue downward vertical handoff when the estimated TCP throughput produces positive performance gain, otherwise, it will not issue the handoff. In the simulations, our proposed handoff decision scheme shows better correctness than a conventional handoff scheme, RSS scheme. Specially, our proposed scheme shows much better performance on the case that assigns lower bandwidth at WLAN, and on the case that the speed of a mobile node is so high that it stays short at WLAN.

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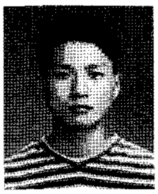

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