WLAN을 이용한 셀룰러망 혼잡도 완화를 위한 호수락제어 성능 분석

(Performance Analysis of Call Admission Control Utilizing WLAN to Mitigate Congestion of Cellular Networks)

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요 약 본 논문에서는, WLAN과 셀룰러망의 중첩된 환경에서 망자원을 효율적으로 하는 호수락제어 방식을 제안한다. 제안된 방식은 비실시간 트래픽을 WLAN으로 분산 이동시킴으로써 셀룰러망의 혼잡도를 완화시킨다. 제안된 호수락제어 방식에 대해서 수치 분석과 시뮬레이션 분석을 한다. 시뮬레이션 결과로써, 제안된 호수락제어 방식이 기존의 방식보다 좋은 성능을 보여준다. 특히, 실시간 트래픽 보다 비실시간 트래픽의 높은 입력 트래픽율에 대해서 좀 더 안정적인 QoS를 유지할 수 있다.

키워드 : 호수락제어, 수직적핸드오프, 무선망, 셀룰러 망

Abstract In this paper, we propose a resource effective call admission control(CAC) in integrated WLAN and cellular network. The proposed CAC mitigates the congestion of cellular network by handing over non-realtime traffic to WLAN. We analyze the proposed CAC in numerical and simulation method. The simulation results show that the proposed CAC achieves better performance than normal CAC. Especially, the proposed CAC can sustain desired QoS more robustly against high incoming non-realtime traffic load than againt realtime traffic load.

Key words : call admission control, vertical handoff, WLAN, cellular network

1. Introduction

It is an important issue to accept various quality of service(QoS) of applications in fourth generation(4G) wireless network where different types of wireless networks are overlaid. In order to accept the QoS, the CAC scheme in 4G wireless network should consider efficient use of the different types of network resource.

A CAC scheme maintains a QoS by limiting the number of incoming calls or connections. The CAC in cellular network has focused on the situation that a mobile node moves from one cell to another with maintaining acceptable QoS. Forced termination of an ongoing call is less desirable than blocking a new call, so efficient call handling scheme to reduce the handoff blocking probability(or call dropping probability) has been much studied. Guerin [1] proposed a guard channel, a fixed number of channels reserved for handoff calls, in order to guarantee call dropping probability (CDP). Ran [2] proposed a CAC scheme reducing CDP for realtime and non-realtime traffic and analyzed the proposed scheme. Xhafa [3] developed an analytical framework for dynamic priority queuing of handover calls. Kim [4] proposed a

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light-weighted CAC to alleviate the heavy computation overhead for the decision to accept calls or connections.

As 4G wireless network emerges, multiple different types of wireless networks are overlaid, with each providing varying access bandwidth and coverage level. Due to the seamless connection and global mobility requirements, a call in one particular network must be able to be handed over to another network transparently. 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 [5,6].

The vertical handoff is different with the conventional handoff, horizontal handoff, in that the vertical handoff is not a mandatory, but an optional procedure to connect to another wireless network. the CAC scheme should consider the vertical handoff in 4G wireless network for efficient use of the different types of wireless network resources. There are a lot of studies for the efficient use of 4G wireless network resources.

Zhu [7] proposed a cost function that can produce optimized use of network resource from the variety of users and network valued metrics in wireless LAN(WLAN) and General Packet Radio Service(GPRS) integrated environment. With the proposed cost function, they achieved improved throughput for active sessions. Son [8] proposed a vertical handoff scheme for the best selection to meet or optimize QoS requirements. The QoS requirements can be performance metric by user's preferences, service application, and network condition in Universal Mobile Telecommunications System(UMTS) and WLAN integrated environment. Chen [9] proposed a vertical handoff decision to achieve efficient interface management that gives a better power balance and performance in WLAN and GPRS integrated environment. Nasser [10] proposed a vertical handoff decision function based on cost of service, security, power consumption, network conditions, and network performance. Their evaluation and analysis are based on WLAN and WWAN integrated environment. Calvagna [11] proposed a vertical handoff decision to reflect IP-based applications. For example, a triggering policy which simply switches to any better access network as soon as available, could disappoint the user with possibly frequent connection discontinuities. Depending on the running applications, the performance would not necessarily improve in WLAN, UMTS, and BLUETOOTH integrated environment. McNair [12] indicated the situations that the change in connection may be initiated by the user or may be initiated by the network, transparent to the user. The former situation is when a user may choose to access a wireless LAN to send a large data file, but may choose the cellular network to carry on a voice call. The latter situation is when a network may decide to hand over a stationary data to a WLAN in order to increase bandwidth availability for mobile users in a 3G cellular network. But there is no further analysis

The studies about selecting optimal wireless network is restricted to a terminal mobile node. In the sense of the CAC for overall network performance in 4G wireless network, Yu [13] and Niyato [14] are the studies about efficient use of wireless network resources. Yu [13] proposed an optimal joint CAC scheme for multimedia traffic in an integrated WLAN/CDMA(Code Division Multiple Access) system with vertical handoff, which maximizes overall network revenue while satisfying several QoS constraints in both the WLAN and the CDMA network. However, they assumed all calls can move over heterogeneous wireless networks without tearing down the calls. They did not consider the different feature of realtime traffic and non-realtime traffic in that the voice call, one of realtime traffic, cannot move between cellular network and WLAN without violating the QoS because there must be vertical handoff latency in interworking of cellular network and WLAN(refer [15]), and WLAN cannot provide as good as QoS that cellular network can provide. In addition, the proposed CAC requires the theatrical optimal admission algorithm, and that must produce heavy computational overhead.

Niyato [14] proposed CAC using 4 thresholds to minimize handoff CDP. They considered the different features of realtime and non-realtime traffic by allowing only non realtime traffic to be handed over to WLAN. However, they did not present detail model and analysis for the proposed idea and the performance.

Yu [13] and Niyato [14] presented new CACs for 4G wireless network, but Yu [13] assumed that realtime and non-realtime traffic can move over different types of wireless network. Niyato [14] considered the difference feature of realtime and non-realtime traffic, but they just present the rough idea without detail model and analysis about it.

In this paper, we propose a CAC that handle the admission control at cellular network with utilizing WLAN resource. The proposed CAC hands over non-realtime traffic to WLAN to mitigate cellular network when congestion occurs. So the usual signal strength based handoff initiation may not be enough in the proposed CAC, and the congestion at cellular network is additionally considered. This may result in reducing call blocking probability (CBP) and CDP of realtime and non-realtime traffic of cellular network. Realtime traffic is not considered to be handed over to WLAN because it requires stricter QoS guarantee than that provided by WLAN and cellular network cannot provide available channels to the realtime traffic always when it returns to the cellular network. The proposed CAC adds to normal CAC the proposed algorithm that non-realtime traffic can be handed over to WLAN to alleviate cellular network. The normal CAC means a CAC that does not have means to utilize WLAN resource.

Among many CACs used so far in the conventional cellular network, we adopt dynamic partitioning CAC for the normal CAC due to its superiorly and popularity. But we assume the dynamic partitioning CAC does not have a partitioning algorithm because different partitioning algorithm can produce different performance, so it also could be complete partitioning method. The feature of performance gain by the proposed CAC for the different partitioning algorithm can be analyzed further, but this is not our focus in this paper.

We contribute numerical analysis and simulation analysis of a CAC model utilizing WLAN resource based on a normal CAC. Simulation experiments are conducted to validate the performance of the proposed CAC. In the simulations, we assume that WLAN is overlaid by cellular network, and non-realtime traffic can be handed over between the WLAN and the cellular network. We measure CBP and CDP of cellular network, and compare them with those of the normal CAC that is assumed that it does not have means to utilize WLAN resource to mitigate congestion of cellular network. It is easily expected that the proposed CAC shows better CBP and CDP than the normal CAC. In the simulation results, we want to figure out the feature or behavior of the proposed CAC against the normal CAC rather than just the performance gain itself. The paper is organized as follows. Section 2 describe the proposed CAC in cellular network and WLAN integrated environment. After numerical analysis in Section 3, simulations are performed and the results are presented in Section 4. Finally, Section 5 concludes the paper.

2. The Proposed Call Admission Control

The objective of the proposed CAC is to reduce CBP and CDP of the traffic in cellular network by utilizing plentiful WLAN bandwidth. To reduce them, the proposed CAC mitigates the congestion of cellular network by handing over non-realtime traffic to WLAN. In the proposed CAC, the congestion at cellular network forces non-realtime traffic to move to WLAN by downward vertical handoff. Some portions of traffic handed over to WLAN may return to the cellular network later, and this issues upward vertical handoff. The vertical handoff and its impact on QoS is explained in 2.1, and the system model of the proposed CAC model is explained in 2.2.

The integrated wireless network of WLAN and cellular network is a typical example for the situation about vertical handoff. The cellular network has evolved to the third generation(3G), and the IEEE 802.11 WLANs have proliferated because it does not require license and provide much higher bandwidth than the cellular network. The complementary characteristics of the 3G cellular network and the WLANs promote their interworking. The interworking process and scenario are considered in 3GPP for standardization [16]. Interworking scenarios are defined in 3GPP to implement the 3GPP/WLAN interworking.

In our proposed CAC, cellular network is able to keep CBP and CDP in desired level by handing over the non-realtime traffic to WLAN. In order to access the WLAN, the Authentication, Authorization, and Account(AAA) at WLAN has to acquire the interworking permission from AAA at cellular network [16]. This is for security and billing. The security and billing issues caused by the interwork are also another important research issues, and we leave them out of this paper.

2.1 Vertical Handoff

In 4G wireless network, different types of wireless networks are co-existed with overlaid, and a popular example is that WLANs are overlaid by cellular network, as shown in Fig. 1. The mobile node which goes into a WLAN area may take a new connection of the WLAN or may continue the connection of the cellular network. That is, downward vertical handoff is not mandatory but optional because the mobile node is able to stay with connected to cellular network without WLAN connection.

For realtime traffic, the QoS sustained at circuit switched network like cellular network cannot be handed over to packet switching network like WLAN because the QoS could be violated due to the congestion control scheme of WLAN. The realtime traffic also suffers the call drop because cellular network cannot provide available channel whenever the realtime traffic returns to cellular network after it moves to WLAN. Therefore, the proposed CAC hands over only non realtime traffic to WLAN.

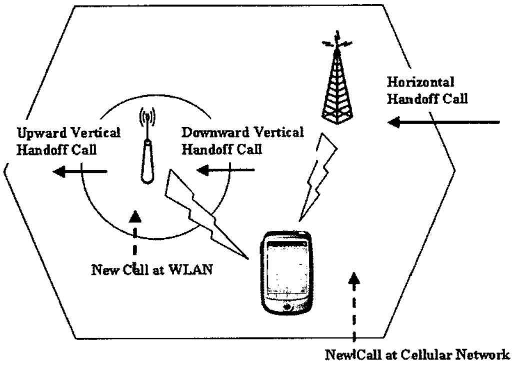

Fig. 1 The Vertical Handoff Situation

2.2 System Model

With the cellular/WLAN interworking, the resources of the two networks can be regarded as a sharing resource. The traffic loads should be properly distributed to the cellular network and WLAN by admission control.

We proposed a CAC that considers the environment where cellular network and WLAN integrated. The integrated architecture of base station and access point is proposed in Fig. 2. There are three types of traffic channels. Designated RT and NRT channel are dedicated for realtime(RT) and non-realtime(NRT) traffic transmission, respectively. The Guard channels can be used by either type of traffic. The total bandwidth assigned in a cell is divided by 3 parts of channelized bandwidth, and each part is assigned to each type of channel. Additionally, any of RT and NRT traffic of handoff calls can reside at Guard channel.

Due to the soft capacity of CDMA, CAC in CDMA system is different from those in Frequency Division Multiple Access(FDMA) and Time Division Multiple Access(TDMA). In Wideband-CDMA(W-CDMA), it is important to satisfy the required QoS of the calls, which is expressed in Signal to Interference Ration(SIR) [17]. For CDMA, the Guard Channel can be understood as the additional capacity that can be assigned for the dropped handoff calls on first request.

RT traffic is blocked if legitimate channels are all in use on its arrival. On the contrary, NRT traffic would be queued in a buffer if legitimate channels are busy. The task of the call admission controller is to accept or reject incoming call in order to maintain the desired QoS of existing calls. The call acceptance decisions shown in Fig. 3 are based on the following rules.

- A newly arriving RT calls are accepted if there are available RT channels.
- A newly arriving NRT calls are accepted if there are available NRT channels.
- Handoff RT calls are accepted if there are available RT or Guard channels.

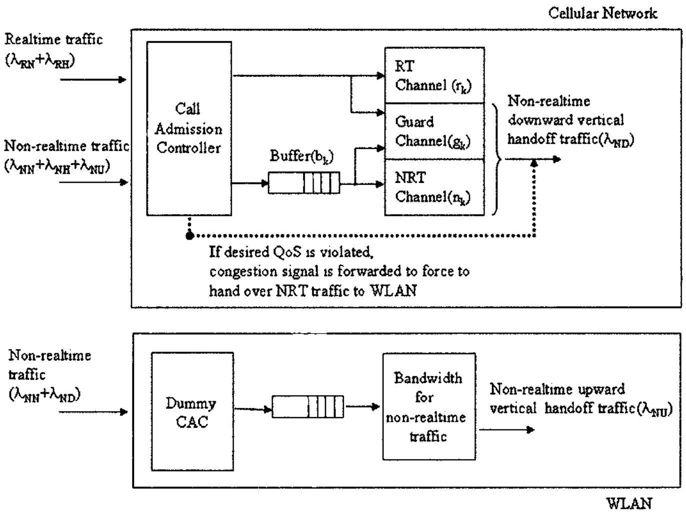

Fig. 2 The Proposed CAC Model

- Handoff NRT calls are accepted if there are available NRT or Guard channels.
- CBP and CDP are updated, and congestion will be signalled to hand over possible NRT traffic to WLAN if the desired QoS is violated.

The congestion signal is issued when the desired QoS is violated. In the proposed CAC, the QoS is determined by CBP and CDP for RT traffic because RT traffic is more sensitive to CBP and CDP than NRT traffic.

The proposed CAC adds the proposed scheme shown in Fig. 3 to normal CAC. We adopt dynamic partitioning CAC as the normal CAC, but we do not have the partitioning algorithm, because the

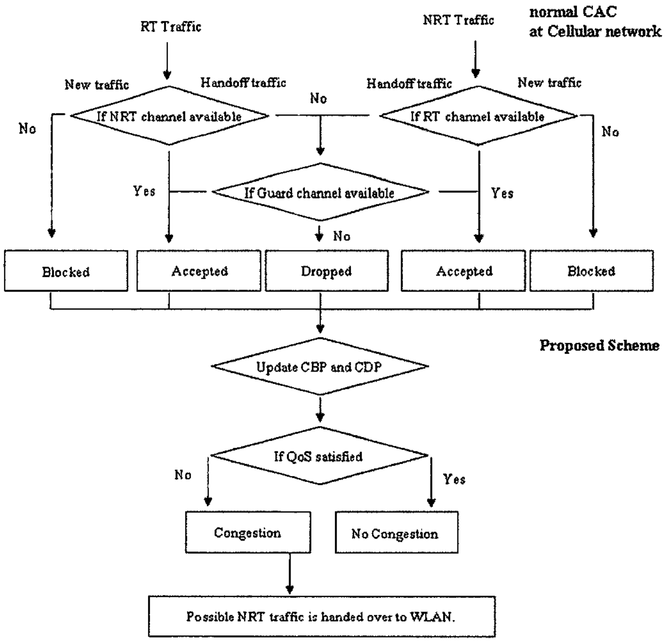

Fig. 3 The Proposed CAC Algorithm

performance of the proposed CAC should be different by the partitioning algorithm. This also can be called complete partitioning. The proposed scheme updates CBP and CDP for the decision to generate congestion signal. When congestion occurs at the proposed CAC, possible NRT traffic will move to WLAN. This makes the arriving rate and service time of NRT traffic (λ_{NN}, λ_{NH}, and $\frac{1}{\mu_D}$ in the equations (1)-(3)) decrease because some of new and ongoing NRT traffic will not occupy the channels of cellular network. This affects on CBP and CDP (the equations (5)-(8)). The CBP and CDP will be fluctuated whenever congestion occurs.

There are two types of architecture for the integrated resource management of cellular network and WLAN, tightly coupled architecture and loosely coupled architecture. In tightly coupled architecture, where cellular network and WLAN are tight with an integration at the access network level or in the core networks, the two networks are maintained in a domain, so interworking works well. On the other hand, in loosely coupled architecture, where interworking is even looser when the two networks are integrated beyond the core networks and usually through an external Internet Protocol, the two networks will communicate through Internet Protocol [16].

Our proposed CAC can be based on either of the two architectures, but we prefer tightly coupled architecture in this paper. The NRT traffic has to be transferred from cellular network to WLAN, and this requires an additional delay for the interworking, security, and billing maintenance. Most of NRT traffic is carried by TCP protocol and the TCP protocol regards the NRT traffic lost if the process takes longer than expected duration. The recovery process for the lost NRT traffic causes the degradation of TCP performance seriously [18,19]. From this reason we prefer tightly coupled architecture rather than loosely coupled architecture. In addition, loosely coupled architecture may cause a trouble in inter-domain access due to the different policy.

Our proposed CAC requires the interworking between WLAN and cellular network. The interwork [16] should allows the access to WLAN through AAA for the purpose of security and billing. So our proposed CAC restricts WLAN to non-public WLAN that is managed in the same access permission of the cellular network.

3. Numerical Analysis

The mobility of mobile subscribers has a great effect on the QoS provision of wireless networks. The arrival processes of new and handoff calls for both RT and NRT calls are assumed to be the Poisson process with mean arrival rates, λ_{RN}, λ_{RH}, λ_{NN}, and λ_{NH}, respectively. Moreover, the arrival processes of handoff calls for both RT and NRT calls are the functions of the average number of call holding channels in adjacent cells. If we assume that some portions of calls in WLAN networks move to cellular networks before service completion, the arrival rate of upward vertical handoff calls is given by λ_{NP}. The total arrival rate of calls in the current cell, therefore, is

$$\lambda_{total} = \lambda_{RN} + \lambda_{RH} + \lambda_{NN} + \lambda_{NH} + \lambda_{NP} . \qquad (1)$$

For the sake of analytical tractability, channel holding time is traditionally provided under the exponential distribution [20,21] as given by T_{CR} and T_{CN} for RT and NRT traffic with mean E[T_{CR}] and E[T_{CN}] given by,

$$E[T_{CR}] = 1/(\mu_R + \mu_D) . \qquad (2)$$

$$E[T_{CN}] = 1/(\mu_N + \mu_D) . \qquad (3)$$

$1/\mu_R$ and $1/\mu_N$ are the mean of call holding time for RT and NRT traffic, and $1/\mu_D$ is the mean of cell duration time of a mobile node which produces the traffic. They all are exponentially distributed. In order to denote the proposed CAC (see Fig. 2), four dimension Markov chain is given by (i, j, k, l), where

i is the number of RT calls in rk(number of channel for RT),

j is the number of RT calls in gk(number of channel for Guard),

k is the number of NRT calls in gk and bk(number of channel for buffer),

l is the number of NRT calls in nk(number of channel for NRT).

We can obtain the steady state probability set

P(i, j, k, l) of the system to be in state (i, j, k, l). These probabilities are related to each other through the global balance equations. All possible steady state can be classified into four parts, according to the number of each service calls of i and l state.

- When both i and l are not full (i.e. $0 \le i < rk$ and $0 \le l < nk$), both j and k are empty (i.e. j=0, k=0).
- When i is not full and l is full (i.e. $0 \le i < rk$ and $l = nk$), j is empty and k can be from 0 to gk + bk (i.e. $j = 0$ and $0 \le k \le gk + bk$).
- When i is full and l is not full (i.e. $i = rk$ and $0 \le l < nk$), j can be from 0 to gk and k is empty (i.e. $0 \le j \le gk$ and $k = 0$).
- When both i and l is full (i.e. $i = rk$ and $l = nk$), j can be from 0 to gk and k can be from 0 to gk-j+bk (i.e. $0 \le j \le gk$ and $0 \le k \le gk - j + bk$).

Thus, the sum of all state probabilities is equal to 1, i.e., normalization condition is given by

$$1 = \sum_{i=0}^{rk-1}\sum_{l=0}^{nk-1} P(i,0,0,l) + \sum_{i=0}^{rk-1}\sum_{k=0}^{gk+bk} P(i,0,k,nk) + \sum_{j=0}^{gk}\sum_{l=0}^{nk-1} P(rk,j,0,l) + \sum_{j=0}^{gk}\sum_{k=0}^{gk-j+bk} P(rk,j,k,nk). \quad (4)$$

We can compute all the steady state probabilities P(i, j, k, l)s and the arrival rate of handoff calls (λ_{RH}, λ_{NH}) using SOR(Successive Over Relaxation) iteration method. Furthermore, the following system performance parameters can be obtained from the steady state probabilities.

The CBP of new real-time calls is,

$$P_B^{RT} = 1 - \sum_{i=0}^{rk-1}\sum_{l=0}^{nk-1} P(i,0,0,l) + \sum_{i=0}^{rk-1}\sum_{k=0}^{gk+bk} P(i,0,k,nk). \quad (5)$$

The CDP of handoff real-time calls is,

$$P_D^{RT} = \sum_{l=0}^{nk-1} P(rk,gk,0,l) + \sum_{k=0}^{gk-j+bk} P(rk,gk,k,nk). \quad (6)$$

The CBP of new non-real-time calls is,

$$P_B^{NRT} = 1 - \sum_{i=0}^{rk-1}\sum_{l=0}^{nk-1} P(i,0,0,l) + \sum_{j=0}^{gk}\sum_{l=0}^{nk-1} P(rk,j,0,l). \quad (7)$$

The CDP of handoff non-real-time calls is,

$$P_D^{NRT} = \sum_{l=0}^{rk-1} P(i,0,gk+bk,nk) + \sum_{j=0}^{gk} P(rk,j,gk-j+bk,nk). \quad (8)$$

4. Simulation Analysis

We analyze the performance of the proposed CAC in the manner of simulation compared with the normal CAC that does not have means to utilize WLAN resource. The metrics are CBP and CDP for RT and NRT traffic.

4.1 Simulation Environment

As shown in Fig. 1, a WLAN is overlapped by a cellular network, and there is a mobile node. In this environment, the proposed CAC can utilize WLAN resource to mitigate the congestion of cellular network while the normal CAC does not have means to utilize WLAN resource. It is easily expected so is not main concern that the proposed CAC shows better performance than the normal CAC, that is, less CBP, CDP due to the added WLAN resources. In this simulation, we will figure out what feature the proposed CAC shows against the normal CAC, in addition that how much the proposed CAC is better than the normal CAC.

We assume that the area of WLAN occupies 20% of the area of cellular network. We assume that RT traffic has desired QoS while NRT traffic does not because NRT traffic can be retransmitted after a loss occurs, so it does not require strict QoS as much as RT traffic requires. The desired QoS is 10^{-2} for CBP(new RT QoS), and 10^{-4} for CDP(handoff RT QoS).

The simulations are performed by our devised program. The program emulates the proposed CAC algorithm shown in Fig. 3. The simulation generates 10^6 incoming events, each of which means an arrival of RT and NRT traffic. It will occupy any available room in designated channels, or will be dropped(or blocked). The inter-arrival time for the incoming events are varied by our intention. As the inter-arrival time goes shorter, the handoff RT QoS is supposed to be violated.

The number of channel for RT(rk), NRT(nk), Guard(gk), and buffer(bk) is 10, 5, 5 and 5, respectively. New RT traffic can take 10 channels, and handoff RT traffic can take additional 5 Guard channels. New NRT traffic can take 5 channels and 5 buffers, and handoff NRT traffic can take additional 5 Guard channels.

4.2 Results and Discussion

In the given fixed traffic load, Fig. 4 and Fig. 5 show the CBP and CDP of RT and NRT traffic, respectively. RT traffic requires desired QoS while NRT traffic does not. When the RT traffic is blocked or dropped more than the desired QoS (noted by new RT QoS and handoff RT QoS), possible NRT traffic will be moved to WLAN to mitigate the cellular network in the proposed CAC. In Fig. 4, handoff RT traffic violates its desired QoS, and the proposed CAC moves the possible NRT traffic to WLAN. This results in that the curve of CDP of the handoff RT traffic go down below the desired QoS. However, normal CAC shows CDP for handoff RT traffic still stays higher than the desired QoS.

The handoff NRT traffic can be handed over to WLAN in the proposed CAC to mitigate the congestion at cellular network. This reduces CBP and CDP of NRT traffic as shown in Fig. 5. This results from that WLAN accepts the NRT traffic without dropping. As tradeoff, the traffic load in the WLAN may become higher.

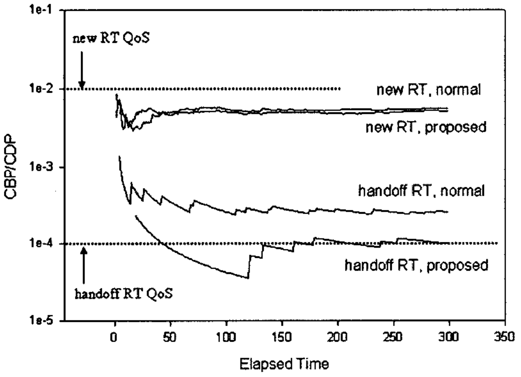

Fig. 4 CBP and CDP of RT traffic: $\rho_{RT}=\rho_{NRT}=4$ where ρ_{RT} and ρ_{NRT} means traffic load of RT and NRT traffic respectively

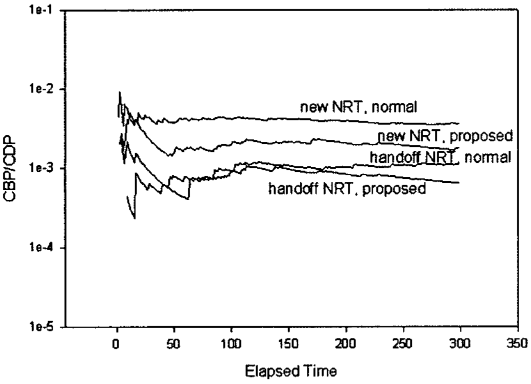

Fig. 5 CBP and CDP of NRT traffic: $\rho_{RT}=\rho_{NRT}=4$

The amount of traffic which is handed over to WLAN is shown in Fig. 6, that could be connected to or be stayed at cellular network if the cellular network is not congested. While the handoff RT traffic violates the desired QoS(see Fig. 4), the NRT traffic is forced to move to WLAN. WLAN does not block or drop the NRT time traffic, so this makes the CBP and CDP of NRT traffic be less than those of normal CAC (see Fig. 5). NRT traffic, which takes a channel with communicating with correspondent node, is forced to move to WLAN, and it is marked as "in-service NRT traffic". This increases like step-shaped because the proposed CAC forces all possible NRT traffic located in the overlapped area to move to WLAN. The "new NRT traffic" is NRT traffic newly arrived at the overlapped area, and it is also handed over to WLAN. This increases as much as the incoming traffic rate to the overlapped area. If the area of WLAN becomes larger, then more NRT traffic can be handed over to WLAN.

Fig. 7 shows the CBP and CDP of RT traffic as RT traffic load increases. In the given new and

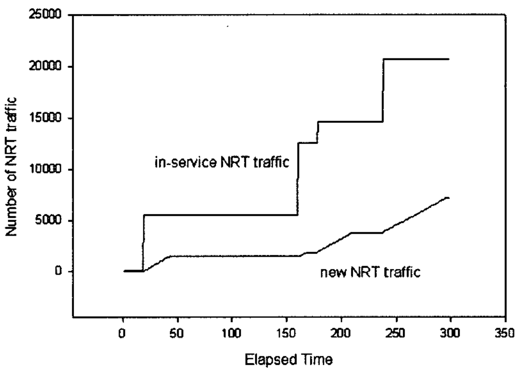

Fig. 6 NRT Traffic Moved to WLAN: "in-service NRT traffic" means the NRT traffic already occupying NRT channel, and "new NRT traffic" means the newly arrived NRT traffic to occupy NRT channel

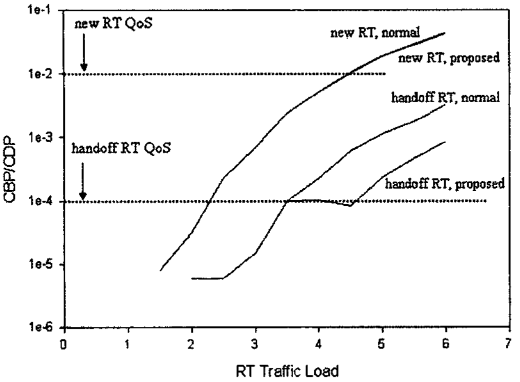

Fig. 7 CBP and CDP of RT traffic: ρ_{NRT} = 4.0.

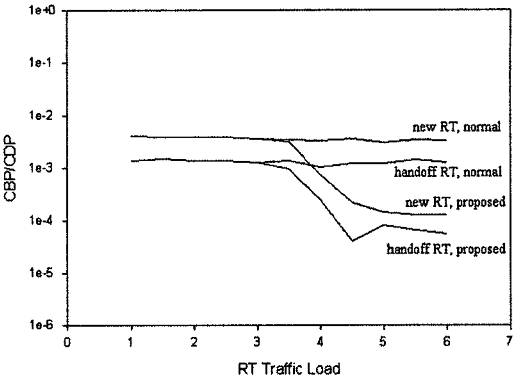

Fig. 8 CBP and CDP of NRT traffic: ρ_{NRT}=4.0.

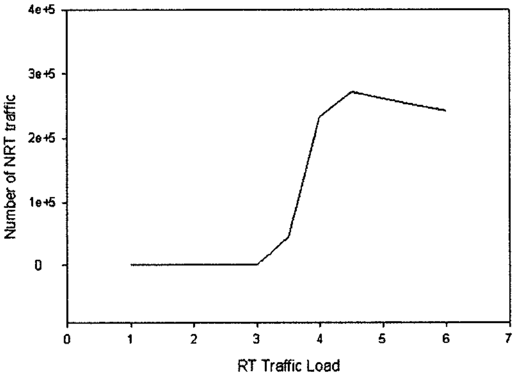

Fig. 9 The Number of NRT traffic Moved to WLAN: ρ_{NRT}=4.0.

handoff RT QoS in Fig. 7, CDP of RT traffic gets violated the given QoS when RT traffic load is 3.5. Then, the proposed CAC moves NRT traffic to WLAN so RT traffic have the benefits from the congestion mitigation at cellular network. Before RT traffic load 4.5, the proposed CAC maintains keeping the desired QoS by utilizing WLAN while the normal CAC goes higher than the desired QoS. Beyond RT traffic load 4.5, the proposed CAC gets higher CBP and CDP than the desired QoS due to the much higher incoming RT traffic load, even though it shows better performance than the normal CAC. On the other hand, new RT traffic does not have any difference between the proposed CAC and normal CAC because new RT traffic has to occupy only RT channel and it can not achieve any advantage from congestion mitigation at NRT and Guard channel.

Fig. 8 shows the CBP and CDP of NRT traffic as RT traffic load increases. Both results of the normal CAC and the proposed CAC is not much affected from the RT traffic load because buffer can alleviate the impact of high RT traffic load on NRT traffic. This makes the handoff NRT traffic does not increase apparently as RT traffic increases. When the RT traffic violates the desired QoS beyond RT traffic load 3.5(see Fig. 7), CBP and CDP of NRT traffic in the proposed CAC drops sharply until RT traffic load 4.5. In this period, a lot of NRT traffic is forced to move to WLAN and this makes CDP of CBP of NRT traffic goes down in the proposed CAC. Beyond RT traffic load 4.5, the proposed CAC does not have enough NRT traffic to move to WLAN to mitigate the congestion so CBP and CDP do not drop any more. This is shown in Fig. 9.

The number of NRT traffic which is moved to WLAN sharply increases between RT traffic load 3.5 and 4.5, but slightly decreases after RT traffic load 4.5 in Fig. 9. When RT traffic load is higher than 4.5, there is not enough NRT traffic to be moved to WLAN because RT traffic can take available channels more due to its higher traffic load.

In these results when RT traffic load increases and this violates a desired QoS, we can figure out the following features. CBP of RT traffic does not have any performance gain with the proposed CAC because the proposed CAC does not hand over RT traffic to WLAN due to the QoS guarantee for RT traffic. CDP of RT traffic achieves positive per-

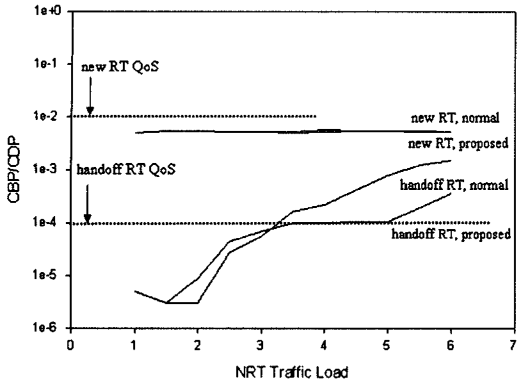

Fig. 10 CBP and CDP of RT traffic: ρ_{RT} = 4.0

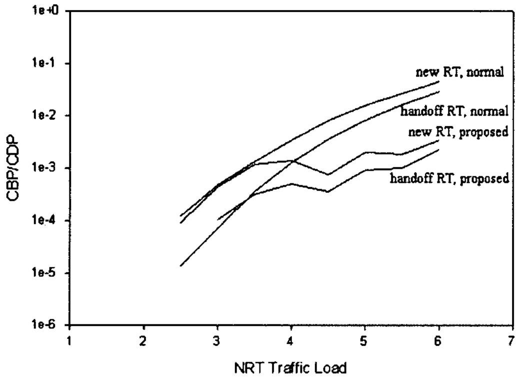

Fig. 11 CBP and CDP of NRT traffic: ρ_{RT} = 4.0

formance gain to RT traffic load 4.5. Beyond the RT traffic load 4.5, the proposed CAC does not guarantee the desired QoS even though it shows better performance than the normal CAC. NRT traffic achieves positive performance gain for all RT traffic load in terms of CBP and CDP. As the tradeoff, WLAN will be congested more as much as the number of NRT traffic forced to be moved to WLAN.

Fig. 10 shows CBP and CDP of RT traffic when NRT traffic load increases. The CDP of RT traffic stays longer below handoff RT QoS than that of Fig. 7 because NRT traffic, which can be moved to WLAN to mitigate the congestion of cellular network, is more plentiful than that of Fig. 7. CBP and CDP of NRT traffic, in Fig. 11, increases as NRT traffic load increases. This is different from the results of the situation that RT traffic load increases.

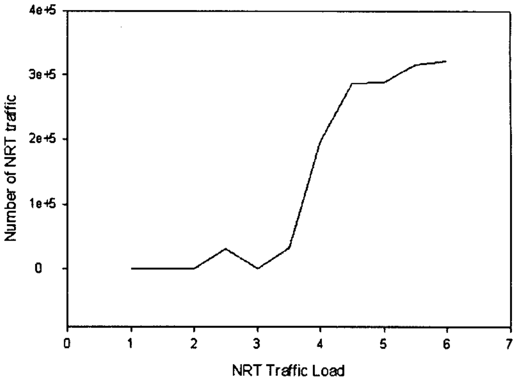

Fig. 12 The Number of NRT traffic Moved to WLAN: ρ_{RT} = 4.0

As shown in Fig. 12, when RT traffic violates the desired QoS(see Fig. 10), the amount of NRT traffic moved to WLAN begins to increase sharply. While the proposed CAC has enough NRT traffic to be moved to WLAN, the handoff RT QoS is sustained in the desired QoS. For the high NRT traffic load, the proposed CAC can sustain the desired QoS more robustly than for the high RT traffic load.

In these results when NRT traffic load increases and this violates the desired QoS, we can figure out the following features. CBP of RT traffic does not have any performance gain with the proposed CAC as also shown in the case that RT traffic load increases. CDP of RT traffic achieves positive performance gain to NRT traffic load 5.0. The NRT traffic load 5.0 is higher than that of the case that RT traffic load increases. This also means that the proposed CAC utilizes NRT traffic to mitigate the congestion of cellular network, so it can sustain the CDP longer in the desired QoS for higher NRT traffic than higher RT traffic load. CBP and CDP of NRT traffic deteriorates its QoS as NRT traffic load goes higher that is not shown in the case that RT traffic load increases. This is because higher NRT traffic occupies not only NRT channel but also buffer that is not occupied by RT traffic even though the RT traffic is generated in high rate.

5. Conclusions

We proposed a resource effective CAC in WLAN and cellular network integrated environment. The proposed CAC can mitigate the congestion of cellular network by moving NRT traffic in cellular network to WLAN because NRT traffic can move between them without seriously deteriorating its QoS. In this paper, we analyzed the proposed CAC in numerical and simulation method. In the simulation results, the proposed CAC has more sustainable in a desired QoS for high NRT traffic load than for high RT traffic load. This results from that there can be more NRT traffic to utilize to mitigate the congestion of cellular network when NRT traffic load increases. However, the QoS for NRT traffic in terms of CBP and CDP goes deteriorated when NRT traffic load increases while this is not shown when RT traffic load increases.

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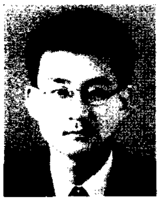

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