ITE Trans. on MTA Vol. 2, No. 4, pp. 327-335 (2014)

Paper

Performance Evaluations of Comfort Route Navigation Providing High-QoS Communication for Mobile Users

Kenji Kanai†, Jiro Katto† (member) and Tutomu Murase††

Abstract To improve Quality of Service in wireless networks while mobile users travel, we introduce Comfort Route Navigation (CRN) which is a navigation system based on a user centric mobility management for next generation wireless networks. CRN provides an optimal route that satisfies user needs, such as obtaining maximum wireless resources. To achieve CRN, we construct an access point (AP) map of Shinjuku city. To reflect quality of APs in this map, we evaluate throughputs at seven public Wi-Fi spots. Based on these observations, we evaluate performance of our CRN via computer simulations and in a real environment. These evaluations conduct that a CRN user could obtain higher communication quality rather than a Shortest Route (SR) user. These evaluations also conclude that CRN gain depends heavily on the quality and location of the best broadband spot.

Keywords: navigation system, route planning, Quality of Service, heterogeneous networks, wireless LANs, mobile user.

1. Introduction

Improving Quality of Service (QoS) in wireless networks is mandatory for mobile users. The use of mobile terminals, such as smartphones and tablet PCs, has become diverse and widespread. These devices have become indispensable tools to keep users connected because they support and complement various wireless interfaces, such as 3G, Long Term Evolution (LTE), LTE Advanced (LTE-A), wireless LANs and Bluetooth. It is well known that communication quality in such wireless networks easily fluctuate because of shared bandwidth among multiple users, degradation of the radio signal, and mobile backhaul congestion. These wireless infrastructures have also various coverage areas. Telecommunications use not only a Wide Area Network (WAN) such as macrocells, but also a short range network like a Wireless Local Area Network (WLAN) such as picocells, femtocells and small cells which may be used in next generation 5G networks. As a result, it is important to select an optimal wireless infrastructure depending on service requirements and users' situations, such as time of day and locations.

Received March 15, 2014; Revised June 12, 2014; Accepted July 23, 2014
† Graduate School of Fundamental Science and Engineering, Waseda University
(Tokyo, Japan)
†† Cloud System Research Laboratories, NEC Corporation
(Kanagawa, Japan)

A Heterogeneous Network (HetNet) is known as a wireless network using different access technologies[1]. To achieve it, three important phases are necessary; "network discovery phase", "network selection phase" and "network switching phase".

We have already introduced a "Comfort Route Navigation (CRN)"[2)-4)], which is an application for network discovery and selection phases in HetNet. CRN can be achieved to provide high QoS communication by a user centric mobility management. Our previous works have not discussed how to achieve this system. They have just evaluated CRN performances in computer simulations using homogeneous scenarios.

In this paper, we evaluate the system by using more realistic evaluation maps based on a real city in Japan, Shinjuku. To construct evaluation maps, we observe throughput characteristics at seven different public Wi-Fi spots around Shinjuku. Then, we employed various throughput characteristic models based on these observations. We evaluate the performance of CRN in homogeneous and heterogeneous scenarios by using these models. Evaluations conclude that CRN could provide higher communication quality than non CRN in computer simulations and a real environment.

The rest of this paper is organized as follows. Section 2 presents related works. Section 3 illustrates details of Comfort Route Navigation. Section 4 reports public Wi-Fi spots evaluations. Section 5 discusses CRN gain evaluation via computer simulations. Section 6 shows experimental validation in a real city. Finally, Section 7 provides the conclusions.

2. Related Works

In HetNet, much research has conducted the cellular and wireless LANs integrated networks. Our Comfort Route Navigation focuses on network discovery and selection phases.

In network discovery phase, it is necessary to recognize the type and quality of network interfaces around mobile devices dynamically. Power-efficient Communication Protocol (PCP)[5] can control the wireless LANs interfaces through cellular networks. However, PCP needs to modify actual cellular systems, so we can say that its approach may be distant. Coverage area information and user location are collected previously[6)7)] by using Global Positioning System (GPS) information. However, these schemes assume that wireless network coverage information is fixed and also pre-recorded. So, it is unclear that how to update these information in real-time. In addition, important parameters, including throughput, are not collected. CRN utilizes cloud computing platforms and collects wireless network information, including location and bandwidth, by using mobile devices, and also CRN could be easy to update the wireless network quality even in real-time.

In network selection phase, it is important to select optimal wireless interfaces by fulfilling QoS requirements from mobile users and/or operators. The optimal wireless interfaces should be selected by service requirements[8], multiple QoS metrics[9] and load-balancing[10]. These schemes do not consider the user mobility management. In our approach, the optimal wireless interfaces are selected by a user's needs and actual geographical pathway. Our CRN is allowed to take even a "longer" route, which is geographically longer than a shortest path, to search an optimal path by achieving user's needs. So we can say that this route is achieved by a user-centric mobility management.

In network switching phase, it is known as vertical handover (VHO). VHO is a mechanism which can be solved to switch different wireless interfaces seamlessly without any degradation of communication quality. One of major solution of VHO for real-time traffic is a bi-cast (soft handover) scheme[11)-13)]. Mobility management has also important factor in this phase. Radio link failures and handover failures are easily caused by moving from one cell to another. Handover for high-velocity users is especially challenging in heterogeneous scenarios[14)15)]. Though our CRN actually does not consider handover schemes in this time, these techniques are useful information.

Much research has also been conducted on navigation systems. NaviComf[16] aids in the navigation of people to their destinations via comfortable paths, which are specified by temperature, humidity, or pedestrian crowds, captured by multi-modal sensors. A navigation software package in Japan, called NAVITIME, provides a flatter route that has fewer stairs or more roof coverage. Similarly, SafeJourney[17] defines the best safe route by considering pavements, overhead bridges and other pedestrian attributes. However these routes are selected among many shortest path candidates. Our CRN considers a user's time cost for an optimal path-finding.

In case of navigation assistance for visually impaired people, verbal instructions should be different context information from sighted people. Visually impaired participants should be guided by incorporated sensory, motion and social contact information rather than textual-structural and area/street information[18]. This paper has described a navigation assistance technique. Though our CRN does not consider how to navigate users, it is useful information to develop our prototype system.

3. Comfort Route Navigation

3.1 A concept of Comfort Route Navigation

Comfort Route Navigation (CRN) is a navigation system which presents an optimal route that satisfies user needs. We call such optimal route "Comfort Route (CR)".

Though normal mobile users will take geographically Shortest Route (SR) to reach their destinations, such route will not always satisfy QoS requirements for some popular applications, such as video streaming services. Generally broadband spots, such as Wi-Fi spots and small cells, have narrow coverage areas. Especially, Wi-Fi Access Points (APs) are usually placed indoors. That is why SR users are force to use narrowband wireless connection like cellular.

A concept of CRN is quite simple. The CRN will navigate mobile users to such broadband spots which are located near SRs. So CRN users could access high-speed wireless connection more efficiently and effectively. Though the CRN users often take extra time, which is defined as time cost, to reach their destinations,

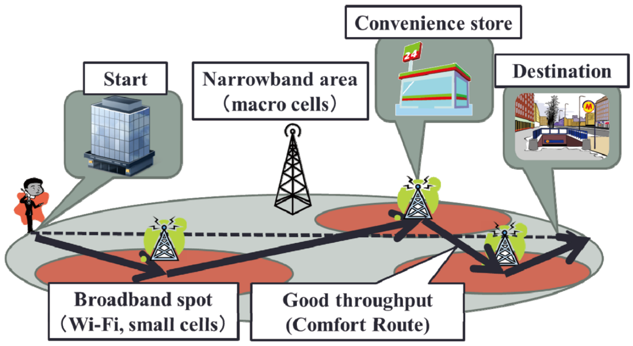


Fig.1 A concept of Comfort Route Navigation.

such cost should be decided by the users. An image of selected Comfort Route (CR) is shown in Fig.1.

3.2 Comfort Route for data delivery

One of a CR that allows mobile users to reach their destinations with maximum wireless resources (e.g., throughput) under constrained conditions, such as maximum time between start and goal spots, was proposed[2]. To create the optimal route, the authors employed the following assumptions: (a) wireless resources can be calculated by the distance between a user and an AP, and (b) each user is allowed to travel toward and/or stay at the broadband spots for a limited time. This implied that although CR users might take extra time to reach their destinations, they could transmit more wireless data compared to SR users.

We evaluated the characteristics of this route in various resource models[3]. We discovered that the gain of this route was the highest when the broadband spot coverage was narrow and available throughput was high. This was because the SR uses fewer broadband spots and the user was forced to use narrowband wireless networks.

In real environments, the available bandwidth in wireless networks fluctuates because of shared bandwidth among multiple users, degradation of the radio signal, and mobile backhaul congestion. We investigated the influence of the CR on QoS characteristics in such situations[4]. We found that users could maximize their resources if they could accurately predict the fluctuations. This is because they could avoid traveling toward and/or staying at such spots. We also found that CRN gain, which is defined as equation (1), heavily depends on the number of APs[4]. The broadband spots get physically closer to the SR as the number of APs gets larger. This means that CRN users can communicate with the broadband spots for longer time because they can shortly travel to these spots. On the other hand, CRN gain decreases gradually as the number of APs gets enough high. This is because the possibility that APs exist on the SR gets larger.

The rest of this paper, we assume that CRN will find such CR.

3.3 Wireless network discovery

To achieve CRN, the users should know the quality of broadband spots. This is similar to network discovery phase in HetNet.

To localize broadband spots, we simply proved an AP map, inspired by paper 6) and 7). This map not only has the location of the APs but also AP conditions such as Service Set Identifier (SSID), Received Signal Strength Indication (RSSI), and types of encryption (e.g., WPA). This map has already been published via several mobile applications and web services such as OpenSignalMaps and WiGLE. These services utilize cloud computing platforms. Each user's smartphone operate as a sensor, records the Wi-Fi conditions around it, and upload the data to a server that adds it to a database. Although we can utilize these services, we employ our own prototype for CRN because AP maps of Japan have not yet been published in the conventional services and they have not been recorded some important parameters for our purposes.

We developed a logging application for Android phones, called mobile logger, which collects context data. The data collected comprise cellular RSS, cellular ID, GPS data, Wi-Fi conditions, and battery status. These data are uploaded to a server and inserted into a MySQL database. We also constructed an AP map on Google Maps that refers to this database. When the APs which have the same MAC address are detected in several locations, we need to estimate the actual AP's position among many candidates using RSSIs. Since RSSI values are larger, which means that a mobile device is physically closer to an AP, we simply select the location that has the highest RSSI value among the candidates. Note that this process is applied to each MAC address to recognize many APs around mobile users. We collected context data in Japan, by using an Android phone for approximately one month. The number of detected APs was approximately 6050, including private Wi-Fi APs, among more than 46000 candidates. An example of actual AP map in Shinjuku, one of major cities in Japan, is shown in Fig.2. In Fig2, colored markers show the estimated AP's positions and each color shows a service provider. Note that, in this case, the detected APs are appeared only outside because we simply use Global Positioning System (GPS)

Fig.2 An example of our Wi-Fi spots map in Shinjuku. Markers show the estimated AP's positions.

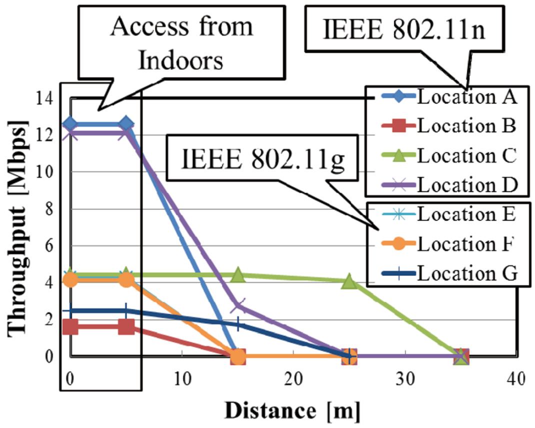


Fig.3 Throughput characteristic models observed at the seven locations.

to get the location information. So, the accuracy and indoor localization is our future work.

3.4 Communication quality awareness

CRN users also should know communication quality at broadband spots before the users actually travel through. This can be achieved by the available bandwidth estimation and prediction technologies[19)-21)].

Bandwidth estimation technologies are based on packet pair and packet train methods. PathQuick[19)], which is used in real-time multimedia communication, can quickly complete the estimation of the latest available bandwidth. Bandwidth prediction technologies utilize the cloud computing for collecting current network performances, such as throughputs, packet losses, and delay. PROTEUS[20)] successfully forecast the short-term performance in cellular networks. The next 200 seconds of TCP throughput fluctuation in cellular and Wi-Fi networks can be also predicted by constructing a stochastic model of TCP throughput, which is a mixture of stationary and non-stationary states[21)].

In this paper, we assume that CRN users could know current and future available bandwidth at each spot by using these technologies. We just collect the current communication quality at actual public Wi-Fi spots.

4. Public Wi-Fi spots evaluations

Though broadband spots are many candidates, we simply used Wi-Fi. To validate and enhance our previous works, we observed actual throughput characteristics at public Wi-Fi spots around Shinjuku, which is the same area shown in Fig.2. We selected seven different locations. Location A to D were served area by FREESPOT using IEEE 802.11n and location E to G were those by NTT DoCoMo Wi-Fi using IEEE 802.11g. All Wi-Fi APs, except for location C, were placed indoors.

In our experiments, we used an Android tablet PC, which is called ICONIA TAB A500, as a sender. A receiver PC was a windows desktop machine and located in our University. A TCP flow was transmitted and measured in throughput with iPerf for Android for 120 sec. The sender attempted to communicate with each AP at different locations indoors and outdoors.

We employed throughput characteristic models based on the results of these evaluations. We assumed that the available throughput within 5 m of each public Wi-Fi spot was uniform. This assumption is based on paper 3) which shows that communication quality would not change rapidly when a mobile user access from indoors. The throughput characteristic models observed at these locations are shown in Fig.3.

The observed throughputs at all locations decrease drastically when the sender gets far from the APs. Though this behavior is similar to paper 3), we can say that it is much hard to maintain good connectivity with Wi-Fi networks in real environments. The mobile user should access Wi-Fi networks from indoors. This means that SR users no longer use Wi-Fi networks effectively.

5. CRN gain evaluations

5.1 CRN gain and time cost definitions

To evaluate the performances of CRN, we define CRN gain as a ratio of transferred data between CRN and non CRN. The transferred data for CRN is closely related to its required time. So, we also define time cost as a ratio of required time between both users. This value likely shows a ratio of path length. As we discussed in Section 3, non CRN users will take SR when they travel to their destinations. The CRN gain and the time cost are calculated as follows:

$$\text{CRN gain} = \frac{\text{Transferred data for CRN user}}{\text{Transferred data for SR user}} \quad (1)$$

$$\text{Time cost} = \frac{\text{Required time for CRN user}}{\text{Required time for SR user}} \quad (2)$$

5.2 CRN Gain and time cost characteristics

CRN gain closely depends on the time cost. The CRN user is allowed to travel through and/or stay at broadband spots under his limited time. As the limited time gets longer, the user will travel more broadband spots and stay at these spots for a longer time. On the other hand, the SR user has no choice but to access narrowband wireless networks because there would be no broadband spots on their travel.

CRN gain also closely depends on the quality of broadband spots. The CRN gain gets lower as their coverage areas get wider because the both users could communicate with broadband spots. However, the CRN gain gets drastically higher as their coverage areas get narrower and their throughputs get higher because the CRN user could access broadband spots, while the SR user would be forced to access narrowband wireless networks.

Thus, we can conclude that CRN gain heavily depends on a selected CR path, and this CR path is selected by user's time cost and quality of broadband spots, and also the number of broadband spots as described in Section 3.2 and also by referring our previous works[3)4)]. Especially, we expect that the CR path is easily diverse by changing the time cost as the number of broadband spots gets enough high. So, in this paper, we assumed that the number of broadband spots is fixed and high enough in our evaluations, and the number of them is 30.

5.3 Evaluation models

At first, we evaluate the performances of CRN via computer simulations. The topology of our simulation maps was an 80×80 square lattice, with two adjacent vertices being 5 m apart. The mobile user moved from a start spot (10, 40) to a goal spot (70, 40) at 1 m/s. Adopted mobility model was a constant velocity model. In this scenario, the shortest time was 300 s. Our maps had 30 broadband spots, and all spots were randomly placed in each map. We assumed that these spots had the same throughput characteristics as those shown in Fig.3. Though a mobile user can access the narrowband wireless networks from anywhere, the user will switch to the broadband spots within their coverage areas without any handover overheads. Selected CRs are guaranteed the best route because we adopt Depth-First Search algorithm, which is known as full search algorithm, to find the optimal route.

5.4 Effects of quality at broadband spots

To evaluate effects of quality at broadband spots, we selected three throughput characteristic models from Fig.3. The definitions are shown as follows:

(1) High-speed but NLoS (None-Line-of-Sight) (model A): an AP is placed indoors. It can provide a high-speed wireless network when the mobile user access from indoors. This model is fitted the results of location A and D. In this case, we adopted that of location A.

(2) Middle-speed and LoS (Line-of-Sight) (model B): The mobile user will keep a LoS condition. An AP can provide a middle-speed wireless network indoors and outdoors. This model is fitted the results of location C.

(3) Middle-speed but NLoS (model C): This model is similar to the model A. An AP can provide a middle-speed wireless network when the mobile user access from indoors. This model is fitted the results of location B, E, F and G. In this case, we adopted that of location F.

Note that the throughput transition of each model is completely followed as shown in Fig.3. The available throughput is uniform within 5m from an AP and then decrease linearly per 10m.

We employed 1000 different maps in each model for homogeneous scenarios. We also used 1000 combined maps in which three models are combined and scattered randomly in one simulation map for heterogeneous scenarios. To employ 1000 combined maps, we randomly picked up 30 APs among three models, such as the AP at location A, C and F shown in Fig.3, and also randomly computed these center positions within 80×80 square lattice. Note that all 30 AP positions are different on each map, though APs are allowed that their coverage areas are overlapped. The available throughput for the narrowband area was uniformly 1.0 Mbps, which is based on actual measurement value for LTE using iPerf for Android. In these evaluations, the time cost was changed 1 to 2. The CRN user would take a shortest route when the time cost is 1. However, the CRN user could take a longer route to travel through some broadband spots as the time cost gets larger.

Average results and examples of selected CRs in case of model A are shown in Fig.4 and Fig.5, respectively.

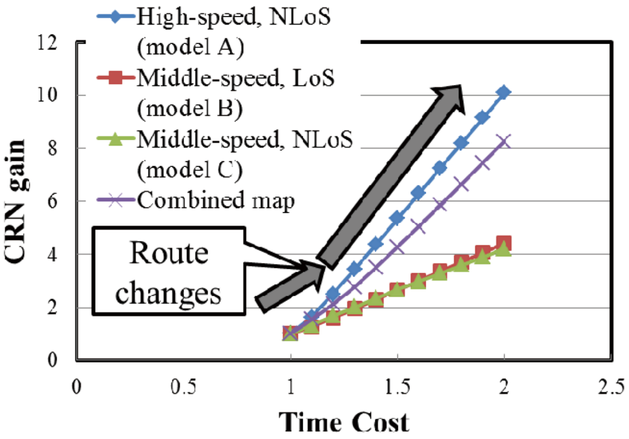


Fig.4 CRN gain characteristics depended on different throughput characteristic models.

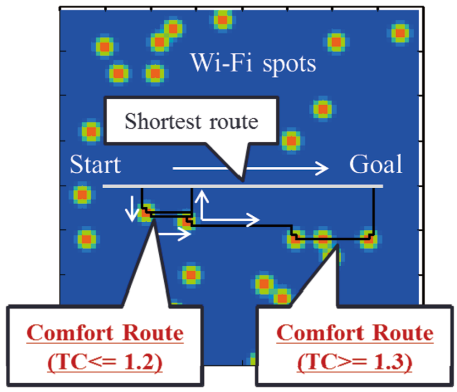


Fig.5 Examples of selected CRs depended on the time costs in case of model A. (TC: Time Cost).

The CRN gains in homogeneous and heterogeneous scenarios are basically the same characteristics.

As shown in Fig.4, CRN gain strongly depends on the ratio of throughput for the broadband spots and narrowband area. The mobile user has no need to travel toward the broadband spots when the both throughputs are similar as shown in the results of model B and C. However, when the throughput gap gets larger, the CRN user will obtain great benefit as shown in the results of model A and combine map.

We also find that the coverage of broadband spots have little influence on CRN gain as compared between model B and model C in Fig.4. The available throughput gets drastically decrease when the mobile user gets far from the APs. This means that the mobile user should get close to the APs even within their coverage area.

The CRN gain of combined model, which is indicated the heterogeneous scenario, is also as high as that of model A. This means that the CRN user could travel through the best broadband spots even if the number of them are only few. Then we can say that CRN user could obtain higher communication quality rather than the SR user in both scenarios because the CRN user just reaches the best broadband spots. We can also say that network discovery technologies are quite important for our CRN.

As described in Section 5.2, CR path selection is closely related to the time costs. As shown in Fig.4, in case of model A and combined model, the CRN gain increase speeds are changed as the time cost gets more than 1.2. This means that selected CR paths are changed. An example of CR path diversity is shown in Fig.5. The CRN user will move actively to the other spots to transfer more data until the time cost gets large as shown in Fig.5. However, when the time cost gets enough large, the CRN user will no longer move, but stay at the broadband spot under remaining time. Generally, it is difficult to provide high communication quality when the mobile user moves actively. That is why the CRN user with large time cost can achieve to transfer huge data.

6. Experimental validation in a real city

6.1 Evaluation models

To enhance our CRN evaluations, we also evaluated and compared the performance of CRN via a computer simulation and experiments in a real environment by using evaluation maps of the real city, Shinjuku in Japan. Though simulation model is almost the same as described in Section 5.3, we reflected the actual throughput of broadband spots in Shinjuku. We selected 6 DoCoMo Wi-Fi spots, which are placed indoor. To employ throughput models for simulation experiments, we measured the available throughput on each Wi-Fi spots. Though throughput evaluations were similar to Section 4, we only evaluated the throughput from indoor. Note that we use a Galaxy J SC-02F as a sender device, and a Linux server, which is located in our university, as a receiver, and also all Wi-Fi spots adopted IEEE 802.11n. A TCP flow was transmitted and measured in throughput with iperf for Android for 60 sec at each Wi-Fi spot. The each available throughput shows the average. We assumed that transmission range of each AP was 15 m and the available throughput was uniform within its coverage area. This assumption was roughly based on the actual size of stores where the APs are placed, and also actual observations. Note that the maximum throughput was observed 39 Mbps in this experiment. We adopted LTE as the narrowband wireless networks and also evaluated LTE throughput while whole moving, and its throughput was 5.8 Mbps on average. Similarly, we assume that the throughput of narrowband wireless networks was also uniform. In the simulation experiments, a start spot is (2, 28) and a goal spot is (78, 28), and also the time cost changed 1 to 2.

In real environment experiments, to search optimal CRs by the time cost, we needed to select Wi-Fi spots which the user should travel through. In this case, these spots were found by simulation experiments based on Depth-First Search algorithm. Once the Wi-Fi spots were selected, an optimal path could be selected by using Google APIs. In this evaluation, the SR user only communicated with cellular networks for simplicity. The CR user, on the other hand, communicated with Wi-Fi spots for at least 30 sec because we assumed that transmission range of each AP was 15 m. The CR user manually switched Wi-Fi interface on and off.

6.2 CRN gain results in a real city

Evaluation maps and selected CRs for computer simulations and real environment experiments are shown in Fig.6 and Fig.7, respectively. As shown in Fig.6, since the best Wi-Fi spot is far from the SR, the CR user had not enough time to travel through the best spot as the time cost is lower than 1.5. As the time cost is more than 1.6, the CR user successfully reached the best spot. These characteristics are also indicated in the real environment experiments, which are shown in Fig.7. However, in the real environment, the CR user took more extra time to reach the best spot rather than the simulation. This is because the CR user physically entered the buildings to access Wi-Fi spots with high quality and also the CR paths are affected to actual geographical route. In this case, the CR user took 1.7 longer times to reach the best spot rather than the SR user.

Comparison results of CRN gain are shown in Fig.8. Since CRN gains of real environment are roughly similar to those of simulation, we can prove that our CRN achieves to provide high communication quality in real environment and also our computer simulation works properly. The CRN gains rapidly increase in both experiments because the CR user can use the best Wi-Fi spot. The CRN gains of real environment are lower than those of simulation because the CR path length gets longer in real environment as we previously described.

Transitions of total transmission data and throughput, which is normalized by 30 sec, in real environment are shown in Fig.9 and Fig.10. As shown in Fig.9, there is little contribution of our CRN as the time cost is less than 1.6 because the throughput gap between broadband and narrowband spot was small in this case. However, once the CR user reached the best spot, the user successfully transmitted huge amount of data as

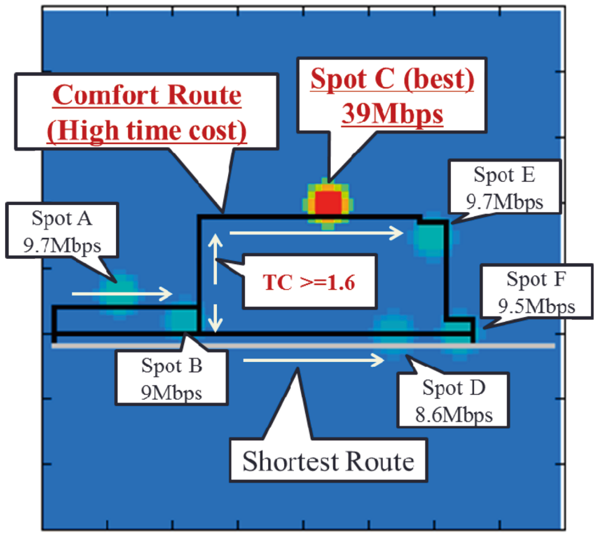


Fig.6 Evaluation map for computer simulations based on a real city, Shinjuku. (TC: Time Cost).

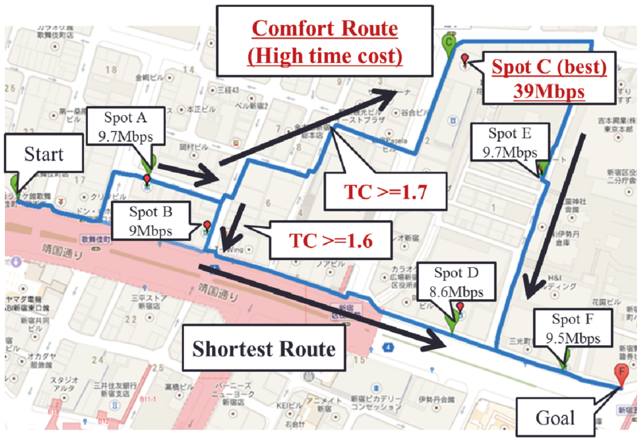


Fig.7 Evaluation map for real environment experiments based on a real city, Shinjuku. (TC: Time Cost).

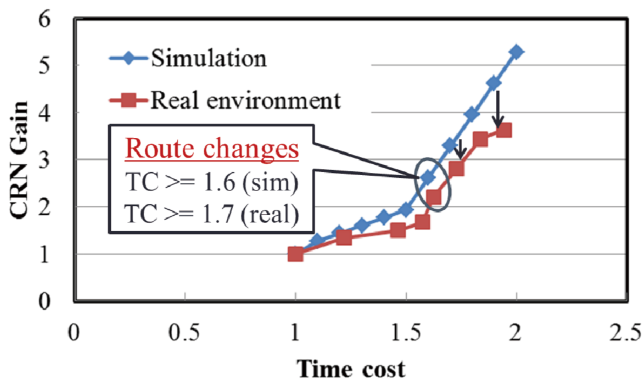


Fig.8 Comparison results of CRN gain between computer simulations and real environment experiments. (TC: Time Cost).

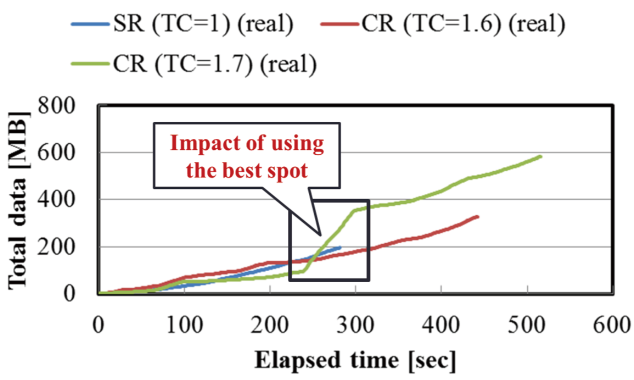


Fig.9 Transmitted data transitions in real environment. (TC: Time Cost).

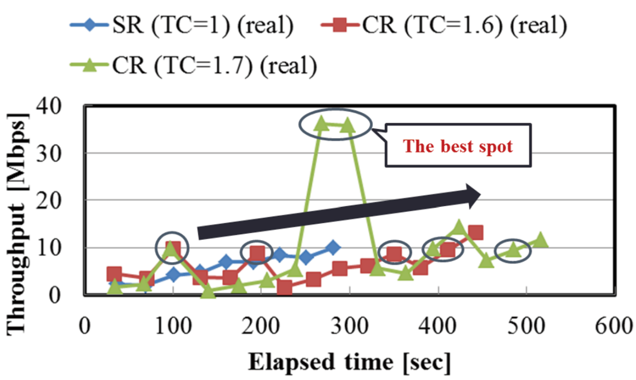


Fig.10 Normalized cellular and Wi-Fi throughput transitions in real environment. (TC: Time Cost).

the time cost gets 1.7. The impact of best spot is also shown in Fig.10. In addition, the available cellular throughputs increase gradually. This may show transition of user population. In Shinjuku, an area around our start position is downtown area. Thus, we can say that cellular networks are also heterogeneous environment even if users locate within macro cells.

6.3 CRN gain characteristics in different 1000 pattern maps

CRN gain and selected CR path depend on the location of the best broadband spot as we previously described. We also indicated CRN gain in each evaluation map and cleared the characteristics of evaluation map in Shinjuku. We evaluated CRN gain using 1000 different maps. We used six broadband spots which have the same throughput model as described in Section 6.1. These broadband spots were randomly placed in each simulation map as previously described in Section 5.4. The time costs were 1.5 and 1.6 in this time. Note that start and goal positions were the same positions of evaluation map in Shinjuku, and also this evaluation map in Shinjuku was one of 1000 different maps.

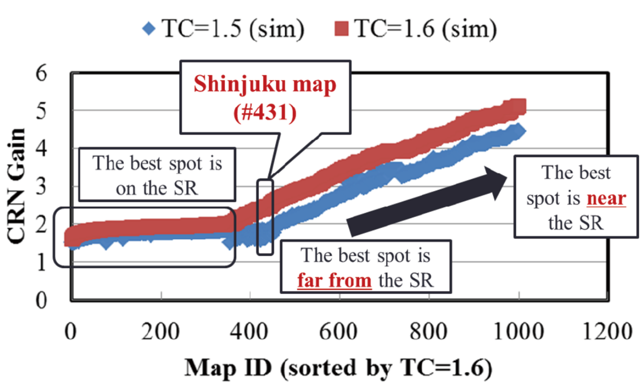


Fig.11 CRN gains of different 1000 maps, including evaluation map based on a real city, Shinjuku. These results are sorted by TC = 1.6. (TC: Time Cost).

CRN gains of different 1000 maps, including Shinjuku map, are shown in Fig.11. As shown in Fig.11, in case that the best broadband spot located on the SR, the CRN gain gets quite low because the SR user could use the best broadband spot. However, the CRN gain gets significantly increase as the best broadband spot gets near but not on the SR. This is because the CR user could take small extra time to reach the broadband spot and communicate with high-speed networks for remained time.

Thus, we can say that CRN gain heavily depends on the location of the best broadband spot, though our CRN did not show the huge gain in case of Shinjuku map. We can also say that throughput estimation and AP localization techniques are important factor for the CRN.

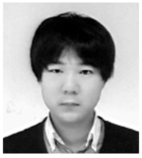
7. Conclusions

In this paper, we introduced Comfort Route Navigation (CRN) to improve Quality of Service (QoS) in wireless networks while mobile users travel. CRN is a navigation system which presents an optimal route that satisfies user needs, such as obtaining maximum wireless resources. Our CRN is based on a user-centric mobility management, which is that we defined the user's time cost as a path-finding metric. To achieve our CRN, we introduced the scheme of dynamic AP localization, including the quality of APs, by utilizing cloud computing platforms. To evaluate CRN performances, we constructed an AP map in Shinjuku, which is one of a real city in Japan. To reflect actual quality of APs in this map, we evaluated the throughput at seven public Wi-Fi spots. Based on these observations, we evaluated the performance of our CRN via computer simulations and in a real environment. These evaluations conclude that the CRN user could obtain the higher communication quality rather than the Shortest Route (SR) user because the CRN could navigate the broadband spots around the user. These evaluations also conclude that CRN gain heavily depends on the quality and location of the best broadband spot.

In the future, we will apply Dijkstra's algorithm to achieve various CRs which provide low-power, low-delay, and good connectivity communications. We will also implement bandwidth estimation and prediction technologies and then construct throughput maps which are detected accurately and cover more wireless infrastructures, including cellular networks. And also we try to develop a Comfort Route Navigation system prototype that covers much wider areas, including indoor.

References

1) I.F. Akyildiz, J. Xie and S. Mohanty: "A survey of mobility management in next-generation all-ip-based wireless systems", IEEE Wireless Communications, 11, 4, pp.16-28 (Aug. 2004)
2) G. Motoyoshi, Y. Sudo, T. Murase and T. Masuzawa: "Advantage of optimal longcut route for wireless mobile users", Proc. IEEE ICC 2011, pp.1-6 (June 2011)
3) K. Kanai, Y. Akamatsu, J. Katto and T. Murase: "QoS Characteristics on a Longcut Route with Carious Radio Resource Models", Proc. IEEE PerCom Workshop 2012, pp.419-422 (Mar. 2012)
4) T. Murase, G. Motoyoshi, K. Sonoda and J. Katto: "Quality of Service of Mobile Users for Longcut Routes with Congested Access Points", Proc. ACM ICUIMC 2013, 40 (Jan. 2013)
5) S.K. Lee and N. Golmie: "Power-Efficient Interface Selection Scheme using Paging of WWAN for WLAN in Heterogeneous Wireless Networks", Proc. IEEE ICC 2006, pp.1742-1747 (June 2006)
6) M. Ylianttila, J. Makela and K. Pahlavan: "Analysis of handoff in a location-aware vertical multi-access network", Computer Networks 47, 2, pp.185-201 (Feb. 2005)
7) D. Kutscher and J. Ott: "Service Maps for Heterogeneous Network Environments", Proc. MDM 2006 (May (2006)
8) W. Chen and Y. Shu: "Active application oriented vertical handoff in next-generation wireless networks", Proc. IEEE WCNC'05, 3 pp.13-17 (Mar. 2005)
9) Q. Song and A. Jamalipour: "A Network Selection Mechanism for Next Generation Networks", Proc. IEEE ICC'05, 2, pp-1418-1422 (May 2005)
10) W. Song, W. Zhuang and Y. Cheng: "Load Balancing for Cellular/WLAN Integrated Networks", IEEE Network, 21, 1, pp.27-33 (Jan. 2007)
11) H. Matsuoka, T. Yoshimura and T.Ohya: "Arobust method for soft IP handover", IEEE Internet Computing, 7, 2, pp.18-24 (Mar. 2003)
12) N. Banerjee, A. Acharya and S.K. Das: "Seamless SIP-based mobility for multimedia applications", IEEE Network, 20, 2, pp.6-13 (Mar. 2006)
13) H. Izumikawa, T. Fukuhara, T. Kishi, T. Matsunaka and K. Sugiyama: "User-centric Seamless Handover Scheme for Real-time Applications in Heterogeneous Networks", IEICE Trans. Communications, E92-B, 3, pp.867-877 (Mar. 2009)
14) S. Barbera, P.H. Michaelsen, M. Saily, K. Pedersen: "Mobility Performance of LTE Co-channel Deployment of Macro and Pico Cells", Proc. IEEE WCNC'12, pp.2863-2868 (Apr. 2012)
15) 3GPP Tech. Rep. 36.839: "Mobility Enhancements in Heterogeneous Networks", v. 11.1.0 (Dec. 2012)
16) C. Dang, M, Iwai, K. Umeda, Y. Tobe, K. Sezaki: "NaviComf: Navigate pedestrians for comfort using multi-modal environmental sensors", Proc. IEEE PerCom2012, pp.19-23 (Mar. 2012)
17) K.H. Yew, Ta Thu Ha, S.D.S.J. Paua: "SafeJourney: A Pedestrian Map using Safety Annotation for Route Determination", Proc. ITSim 2010, pp.1376-1381 (June 2010)
18) N.A. Bradley, M.D. Dunlop: "An Experimental Investigation into Wayfinding Directions for Visually Impaired People", Personal and Ubiquitous Computing, 9, 6, pp.395-403 (Nov. 2005)
19) T. Oshiba, K. Nakajima: "Quick end-to-end available bandwidth estimation for QoS of real-time multimedia communication", Proc. ISCC'10, pp.162-167 (June 2010)
20) Q. Xu, S. Mehrotra, Z. Mao, J. Li: "PROTEUS: Network Performance Forcast for Real-time, Interactive Mobile Applications", Proc. ACM MobiSys'13, pp.347-360 (June 2013)
21) H. Yoshida, K. Satoda, T. Murase: "Constructing Stochastic Model of TCP Throughput on Basic of Stationarity Analysis", Proc. IEEE GlobeCOM'13 (Dec. 2013)



Kenji Kanai received the B.E. and M.E. degrees from Waseda University, Tokyo, Japan, in 2010 and 2012, respectively. His current research interests include wireless and mobile networks and also multimedia communication systems. He is currently working towards the Ph.D. degree in the Graduate School of Fundamental of Science and Engineering, Waseda University. He is a student member of IEEE and IEICE.

Jiro Katto received the Ph.D. degree in electrical engineering from University of Tokyo in 1992. He then worked for NEC Corporation from 1992 to 1999. He was a visiting scholar at Princeton University, NJ, USA, from 1996 to 1997. He then joined Waseda University in 1999 as an associate professor. Since 2004, he has been a professor of the Department of Computer Science and Engineering, Waseda University. His research interest lies in the field of multimedia communication and multimedia signal processing. He is a member of ITE, IEICE, IPSJ, IEEE and ACM.

Tutomu Murase was born in Kyoto, Japan in 1961. He received his M.E. degree from Graduate School of Engineering Science, Osaka University, Japan in 1986. He also received his Ph.D. degree from Graduate School of Information Science and Technology, Osaka University, Japan in 2004. He joined NEC Corporation in 1986 and has been engaged in research on QoS control and traffic management for high-quality and high-speed Internet. His current interests include wireless network QoS control, MAC, transport and session layer traffic control, and network security. He is a visiting professor of Tokyo Institute of Technology. He is a IEEE member and a IEICE fellow.