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Traffic Navigation & Relay: System-Wide Load Balancing Method for Heterogeneous Network Using Route Direction and Packets Relay

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Abstract

We propose the traffic navigation & relay to shorten transmission delay time of the conventional delayed offloading method which is a load balancing scheme of heterogeneous wireless networks. In the original traffic navigation which is a kind of delayed offloading method, the sender user equipment (UE) moves the route that the UE achieves the highest throughput, but transmission delay time is one of the main issues. The proposed traffic navigation & relay can reduce transmission delay time to entrust the packets to other UEs (relayer UEs) if the relayer UEs are able to reach the small cell faster than the sender UE. It was evaluated by computer simulation that the proposed traffic navigation & relay improves the UE's cumulative distribution function (CDF) of transmission completion time by 42 percentage points at 600 s from the conventional method when the density is 125 UEs/km^2.

1 Introduction

The traffic demand for mobile wireless networks has been increasing by 47 percents every year [1]. Heterogeneous networks are important to deal with the increasing traffic demand. The heterogeneous networks are assumed to have two layers, a macro cell network and small cell networks in this paper. The macro cell network has a large coverage, e.g., Long Term Evolution-Advanced (LTE-A). The small cell networks with higher throughput than macro cell have a small coverage, e.g., wireless local area network (WLAN). Using small cell networks superimposed on the macro cell can enlarge the mobile wireless network resource. However, since coverage of small cells is small, the utilization rate of the small cells is low. Therefore, load balancing is necessary to gain the utilization rate of the small cell for the heterogeneous networks.

The delay tolerant traffic of the macro cell networks can be offloaded to the small cell networks when user equipments (UEs) are willing to delay their traffic until the UE reaches the small cell. This concept is called delayed offloading and has been studied [2–5]. However, these scheme has transmission delay time to reach the small cells due to the limitation of UE's moving speed.

In this paper, we propose the traffic navigation & relay for system-wide load balancing using route direction and ad-hoc packet relay which shorten the transmission delay time of the conventional delayed offloading method. The rest of this paper is organized as follows. In Sect. 2, the proposed traffic navigation & relay procedure is explained. In Sect. 3, the transmission delay time of the traffic navigation & relay is evaluated by computer simulation, comparing with conventional schemes. Finally, the conclusions are given in Sect. 4.

2 Proposal of the Traffic Navigation & Relay

2.1 The Traffic Navigation

The proposed traffic navigation & relay is extended the traffic navigation that has previously proposed in [6]. The original traffic navigation realizes to raise the utilization rate of the small cells in a wide area for the load balancing. Fig. 1 shows the concept of the original traffic navigation. A UE (sender UE) that has a non-real-time uplink packet moves to its destination. The UE moves the route that the UE achieves the highest throughput, e.g., the route that has the largest number of the small cells. For realizing the method, the UEs use its location and moving speed information from the Global Positioning System (GPS) and accelerometer. The UEs also have throughput information of small cells using the channel quality map and the traffic map [7–9]. The channel quality map provides the physical channel quality information of each network at each location. The traffic map provides the traffic load information of each network. By using these pieces of information, the UEs calculate throughput of each network at each location. Then, the UE can select the route that the UE achieves the highest throughput when the UE moves through the route. Moreover, by using UE's and small cell's location information and moving speed information, UEs calculate the predicted time t_s to reach the small cells.

The UEs defer transmitting the non-real-time uplink packet to a base station (BS) of a macro cell if the predicted time to reach a small cell is earlier than delay tolerant time of the packet. The packet is transmitted after the UE reaches small cells (in Fig. 1, the packet is transmitted at the time $t = t_s$ via small cell). If the predicted time is later than the tolerant delay time, the UE transmits the packet via macro cell without deferring transmitting. Thus, the traffic navigation gains the small cell utilization rate with keeping tolerant delay time.

One of the main issues of the original traffic navigation is a transmission delay time. The transmission delay time is defined as the time from when the non-real-time uplink packet arises generated until the packet is transmitted via BS or AP. The transmission delay time consists of the predicted time to reach small cell and the packet transmission time via BS or AP which can be calculated by using the channel quality map and the traffic map. Since user prefers to shorter transmission delay time, transmission delay time needs to be shorter even if it is shorter than the delay tolerant time of the packet.

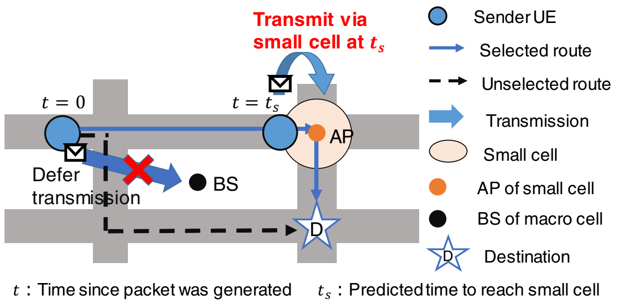


Figure 1. The concept of the original traffic navigation.

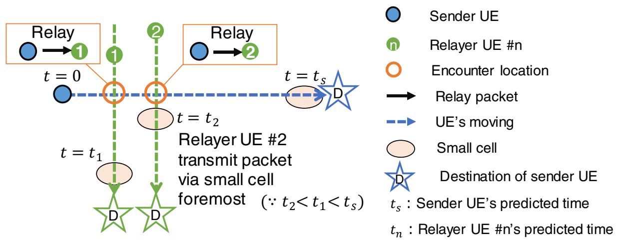


Figure 2. The concept of the traffic navigation & relay.

2.2 Concept of the Traffic Navigation & Relay

The proposed traffic navigation & relay aims to shorten the transmission delay time of the original traffic navigation by using ad-hoc packet relay. Fig. 2 shows the concept of the proposed traffic navigation & relay. There are a sender UE and two relayer UEs. The sender UE has the non-real-time uplink packet. The relayer UE can relay the packet to the AP. They are moving towards their intended each destination, and sometimes they encounter each other. As same as the original traffic navigation, the UEs moves the route which produces the highest throughput with deferring transmit the packet to the BS of the macro cell immediately. In this proposed scheme, the sender UE transmits the packet to the relayer UE by an ad-hoc communication when the relayer UE will reach the small cell faster than the sender UE. In Fig. 2, when the sender UE encounters a relayer UE #1 that reaches the small cell faster than the sender UE, the sender UE copies and entrusts packet to the relayer UE #1. When the relayer UE #1 reaches the small cell, the entrusted packet is sent. When the packet arrives at the server, an acknowledgment (ACK) is broadcast to all relayer UEs through the macro cell in order to command the relayer UE to prevent unnecessary transmission.

Additionally, the transmission delay time can be reduced even further by entrusting the packet with the relayer UE #2 upon encounter, if the relayer UE #2 is predicted to reach the small cell before the relayer UE #1.

2.3 Procedure of the Proposed Traffic Navigation & Relay

Fig. 3 shows the steps of the proposed traffic navigation & relay. The three steps of the traffic navigation & relay scheme using a beacon are explained as follows.

(step 1) As shown in Fig. 3(1), the sender UE broadcasts beacon every beacon period T_B. The beacon includes the sender UE's predicted time to reach the small cell t_s.

The relayer UEs that receive the beacon of the sender UE compares their predicted time to reach the small cell t_{rn} with that of the sender UE t_s.

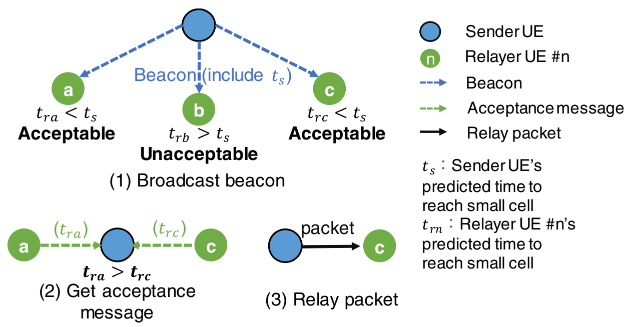


Figure 3. The steps of the traffic navigation & relay.

(step 2) As shown in Fig. 3(2), when the predicted time t_{rn} is shorter than t_s, the relayer UE #n sends the acceptance message which includes the relayer UE's predicted time t_{rn} to the sender UE.

The sender UE receives the acceptance message. When the sender UE receives a number of acceptance messages at the same time, the sender UE compares its predicted time t_{rn}. If the sender UE receives no acceptance message, the sender UE transmits the beacon again after T_B and the traffic navigation & relay steps go back to the step 1.

(step 3) As shown in Fig. 3(3), the sender UE transmits the non-real-time uplink packet to the relayer UE that has the shortest transmission delay time t_{rn}.

The sender UE needs to renew its predicted time as the entrusted relayer UE's predicted time (t_{rc} in the case of Fig. 3 after the packet is entrusted. After T_B passes, this scheme goes back to the step 1.

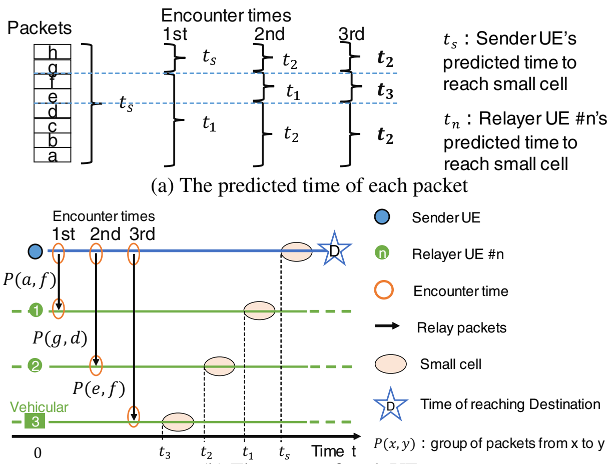
In the next cycle, the sender UE's predicted time in the beacon is renewed (to $t_{rc} - T_B$ in the case of Fig. 3). By a repetition of the 3 steps, the traffic navigation & relay is realized.

Fig. 4 shows a packets relay protocol of the traffic navigation & relay. In the high load situation, the sender UE has a number of packets which original data size is so large that all packets cannot be relayed to the relayer UE in a one-time relay. The packets relay protocol for the divided packets will be described below.

Fig. 4(a) shows predicted time of each packet. There are eight packets a, b, c, d, e, f, g, h. Here, we describe the group of the eight packets as P(a,h) where P(x,y) means the group of packets from packet x to packet y. Each packet has its own predicted time to reach the small cell. The predicted time is renewed when the relay is done. Encounter time means the number of times when the sender UE encounter the relayer UEs. In this protocol, when the sender UE encounters the relayer UE, the packet which has the longest predicted time is preferentially relayed.

In Fig. 4(b) shows status of each UE. There are a sender UE and three relayer UEs. The sender UE, the relayer UE #1 and #2 are pedestrian UE. The relayer UE #3 is a vehicular UE which moves faster than the pedestrian UEs. The horizontal axis indicates the time sequence. Here, because of the difference of moving speed between pedestrian and vehicle, the maximum number of relayed packets among pedestrian UEs and between pedestrian UE and vehicle UE in Fig. 4(b) are assumed 6 and 2, respectively.

At first, in Fig. 4(a), predicted time of P(a,h) is set t_s because if the sender UE does not encounter the relayer UE,



(a) The predicted time of each packet

(b) The status of each UE

Figure 4. The protocol of the traffic navigation & relay.

all packets reach the small cell at the time of t_s. At 1st encounter time in Fig. 4(b), the sender UE encounters the relayer UE #1, and P(a,f) are only relayed because the maximum number of relayed packets is assumed 6. In Fig. 4(a), the predicted time of P(a,f) is renewed as t_1. Then, at 2nd encounter time in Fig. 4(b), the sender UE encounters the relayer UE #2, the P(g,h) which have the longest predicted time is relayed preferentially, and P(a,d) is relayed additionally. In Fig. 4(a), the predicted time of P(g,h) and P(a,d) are renewed as t_2. Finally, at 3rd encounter time in Fig. 4(b), the sender UE encounters the vehicular relayer UE #3, P(e,f) which have the longest predicted time are relayed preferentially. The only 2 packets can be relayed while sender UE and vehicular relayer UE are within communication range. In Fig. 4(a), the predicted time P(e,f) is renewed as t_3. In this way, all packets are sent in as short a transmission delay time as possible.

3 Evaluation of the Traffic Navigation & Relay

3.1 Simulation Environment

Fig. 5 shows the evaluation environment of the simulation. Table 1 summarizes the setup of the simulation. The evaluation area is set as $1200 \times 1200\,\mathrm{m}^2$. The whole evaluation area is in the macro cell coverage. The macro cell throughput is 150 Mbit/s. There are 5 small cells in the center of the evaluation area. The radius of the small cell is 50 m. The small cell throughput is 3.6 Gbit/s. The walkways are arranged at intervals of 20 m in the east-west direction and the north-south direction, respectively. There are two kinds of UEs; the pedestrian UE and the vehicular UE. All UEs are capable of ad-hoc communication, i.e., all UEs are relay UEs. All pedestrian UEs have the non-real-time uplink packets at the beginning, i.e., all pedestrian UEs are also sender UEs. The pedestrian UEs' generation positions and intended destinations are set randomly. The pedestrian UEs move from the initial position to their destinations in the shortest route through the walkways at 1 m/s. To make the pedestrian UE's existence probability uniformly in the evaluation area, the simulation area is set as $2000 \times 2000\,\mathrm{m}^2$, covering the evaluation area. The vehicle UE has no packet at the beginning. The vehicular UEs only move on the driveways at 10 m/s. The driveways, seen as the thick black lines in

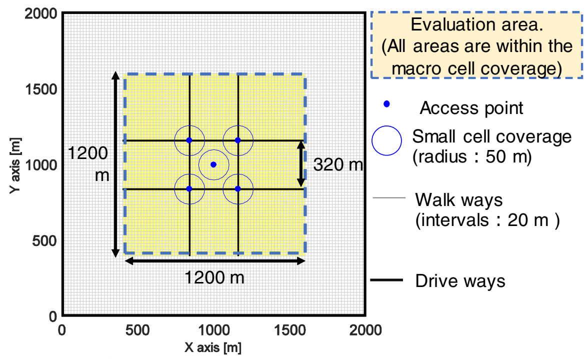


Figure 5. Evaluation environment.

Table 1. Evaluation parameters.

Macro cell throughput	150 Mbit/s
Small cell throughput	3.6 Gbit/s
Relay transmission rate	0.9 Gbit/s
Number of vehicular UEs	50/km
Pedestrian UE's moving speed	1 m/s
Vehicular UE's moving speed	10 m/s
Radius of the beacon reach	20 m
Beacon interval T_B	1 s

Fig. 5, are laid at intervals of 320 m. The number of vehicle UEs per km is 50. The small cells are put at the center of this model and at the intersections of the driveways. The relay transmission rate is 0.9 Gbit/s. In this simulation, we evaluate below 2 items:

1) Pedestrian UE's cumulative distribution function (CDF) of the transmission completion time: The pedestrian UEs' CDF of the transmission completion time is defined as the time from when UE is generated in the evaluation area or enter the evaluation area until the UE gets the ACK. The number of the pedestrian UEs per km^2 is 125. The pedestrian UE's data size at the beginning is changed from 9 Gbit to 36 Gbit as a parameter.

2) Transmission completion UE proportion versus UE density: The pedestrian UE's data size at the beginning is 9 Gbit. The number of pedestrian UEs per km^2 is changed from 25 to 250 as the parameter.

In the above 2 simulations, the evaluation time is 4000 s. We calculated the average of the results of 100 trials.

3.2 Simulated Schemes

In this simulation, we compare the three schemes; 1) immediate transmission scheme, 2) original traffic navigation and 3) proposed traffic navigation & relay. The detail of the 3 schemes is as follows:

1) Immediate transmission scheme: The pedestrian UEs transmit their packets via the macro cell or the small cell immediately. The UEs move from the generated position to the destination through one of the shortest routes.

2) Original traffic navigation: The UEs do not transmit the packets to the macro cell and defer the transmission until reaching the small cell. The UEs move from the generated position to the destination through the shortest route with the largest number of the small cells by the route direction [6].

3) Proposed traffic navigation & relay: It is the same as the scheme explained in Sect. 2. The beacon range and the ad-hoc ranges are 20 m. The beacon interval is 1 s.

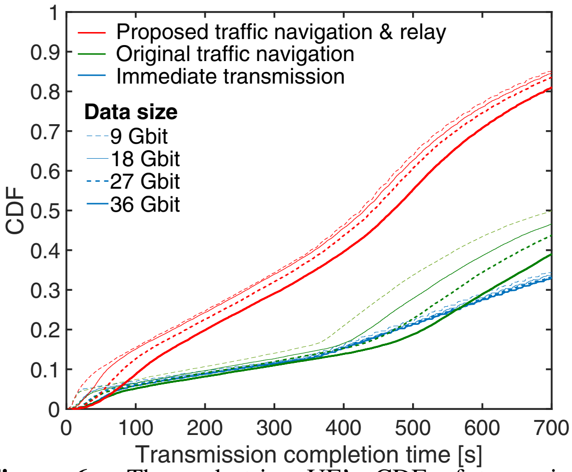


Figure 6. The pedestrian UE's CDF of transmission completion time (the density of pedestrian UEs is $125/\mathrm{km}^2$).

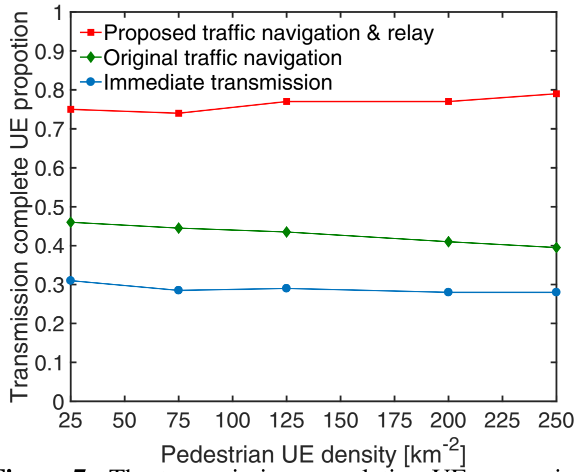


Figure 7. The transmission completion UE proportion at 600 s versus pedestrian UE density (the pedestrian UE's data size at the beginning is 9 Gbit).

Table 2. Pedestrian UE's transmission completion time CDF at 600 s (the density of pedestrian UEs is $125/\mathrm{km}^2$).

scheme	Data size [Gbit] 9	18	27	36
traffic navigation & relay	0.77	0.76	0.75	0.71
traffic navigation	0.43	0.39	0.34	0.29
immediate transmission	0.28	0.28	0.28	0.28

3.3 Evaluation Result

Fig. 6 shows the pedestrian UE's CDF of the transmission completion time. Table 2 shows the value of the pedestrian UE's transmission completion time CDF at 600 s. Except when the transmission completion time is exceedingly small (i.e., less than 90 s), the CDF of the proposed traffic navigation & relay is higher than the others. The proposed traffic navigation & relay can improve by 43 percentage points from the immediate transmission scheme and by 42 percentage points from the original traffic navigation at 600 s where the pedestrian UE's data size at the beginning is 36 Gbit. It is because that the packets can have more chance to be transmitted by the small cell due to the packets relay.

Fig. 7 shows the proportion of transmission completed UE at 600 s versus the density of pedestrian UE. As for immediate transmission scheme, about 30% pedestrian UE can complete transmission by 600 s. As for original traffic navigation, less than 50% pedestrian UE can complete transmission by 600 s. As the number of pedestrian UE increases, the percentage of completion of traffic navigation tends to decrease. Since a lot of UEs get together in the same small cell at the same time, they cannot complete transmission. As for proposed traffic navigation & relay, more than 70% pedestrian UE can complete transmission by 600 s. It is because that the packets can have more chance to be transmitted by small cell due to the packets relay.

4 Conclusion

This paper presented the traffic navigation & relay scheme to shorten the transmission delay time of original traffic navigation for load balancing of heterogeneous wireless networks. In the proposed scheme, the sender user equipment (UE) will entrust the packets to other UEs (relayer UEs) upon encounter if relayer UEs are predicted to reach a small cell faster than sender UE. Therefore, the sender UE can transmit the packets to the small cell with short transmission delay time for load balancing. As the result of computer simulation, it was shown that the proposed scheme improves the UE's cumulative distribution function (CDF) of the transmission completion time by 42 percentage points at 600 s from original traffic navigation when the density is 125 $\mathrm{UEs}/\mathrm{km}^2$ and the sender UE's data size at the beginning is 36 Gbit.

Acknowledgments

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