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RoCNet: Robust Cellular Network for Disaster Communication and Traffic Offloading

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Abstract We have started designing a robust cellular network (RoCNet) that combines infrastructure-based (e.g., cellular) and opportunistic networking for disaster controlling and spatial data offloading. The RoCNet provides communication means without an infrastructure network in some cases such as at the time of disaster by using a store-carry-forward fashion as in the Delay Tolerant Network (DTN). When the infrastructure network is available, the RoCNet facilitates the traffic offloading leveraging the store-carry-forward feature considering a degree of traffic congestion, traffic direction, etc. In this paper, we give an overview of the RoCNet concept and show a simulation result as a proof-of-concept work. The result shows RoCNet can spatially offload uplink traffic in the traffic concentration district to the non-congested area.

Keyword Disaster Communication, DTN, Traffic Offload

RoCNet: 災害時通信機能とトラフィックオフロード機能を兼ね備えたセルラネットワークの提案

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あらまし 筆者らは，セルラに代表されるインフラネットワークと，DTN (Delay Tolerant Network)に代表される定期/不定期に到来する通信機会を有効利用して通信を実施する opportunistic ネットワークとを組み合わせ，災害時通信と通常時のトラフィックオフロードを実現するロバストセルラネットワーク(RoCNet)の検討を実施している．RoCNet は，災害時には DTN のような蓄積・運搬・転送による通信手段を提供する一方，通常時は局所的なトラフィック輻輳を緩和するために蓄積・運搬・転送の仕組みを利用する．本稿では，RoCNet の概要を紹介するとともに，RoCNet によりトラフィック集中エリアのアップリンクトラフィックを輻輳状態でないエリアに空間的にオフロード可能というシミュレーションによる初期評価の結果を示す．

キーワード 災害時通信、DTN、トラフィックオフロード

1. Introduction

In March 2011, we all found that severe natural disaster would make a cellular network unavailable due to, for example, the blackout that results in the stop of base stations(BSs), and unanticipated events such as huge earthquake and/or Tsunami that destroyed facilities [1].

Infrastructure-less communication technology, e.g., adhoc network, delay tolerant network (DTN), etc., has been considered as a promising means for communication in such a challenged situations. DTN introduced a bundle protocol [2] that is a message-oriented overlay on top of existing protocols where the store-carry-forward message switching mechanism is used in communication. However, such infrastructure-less communication technology did not work at the time of disaster unfortunately although the technology has been very popular for researchers for years. When one comes to consider the reason, one possible answer would be that such technology will not be profitable and therefore a commercial mobile terminal does not equip with such technology. In other words, a profitable infrastructure-less technology might be spreading.

On the other hand, growing popularity of mobile data communication has been leading a growing lack of radio resource/capacity in a cellular system [3]. To avoid the cellular network being consistently heavily congested due to the higher traffic demand than anticipated in the future, there are studies targeting to the load balance and the traffic offload. 3GPP has discussed heterogeneous network (HetNet) to offload traffic to low-power nodes called pico cells that are overlaid within a macro network [4]. In the HetNet, the concept of cell range expansion has been also discussed to balance the traffic load through a handover biasing and adaptive resource partitioning. There are studies that aim to balance the traffic load by adjusting handover parameters, which is one of the use cases of self-organized network (SON) also in 3GPP [5]. Multi-RAT (Radio Access Technology) network that we studied [6] can be also considered to be used for offloading traffic by, for example, switching data path to Wireless LAN from cellular. Since all existing schemes as described above are targeting to offload or balance traffic within the same region, the offloading effect might be restricted.

From the above two issues, i.e., a lack of practical disaster communication and highly loaded cellular network, we have started designing a robust cellular network (RoCNet) that combines infrastructure-based and opportunistic networking for disaster controlling and spatial data offloading.

2. Related works

Traffic offloading using the store-carry-forward manner is just a nascent study. In 2010, B. Han, et al., presented the first study ever about cellular traffic offloading using opportunistic communications [7][8]. An application data-set was first sent to *k* users from a content server followed by being propagated to all subscribe users from the *k* users. The study also investigated algorithms about how to choose the *k* users from the all subscribers in terms of the minimization of cellular data traffic. One of evaluated algorithms was Heuristic algorithm that exploited human behavioral character. Y. Li, et al., proposed algorithm by taking the heterogeneity of traffic, user demand, etc., into account [9]. In [10], selection methods of a device act as a bridge between the network and other devices were proposed using the global social graph or the local social communities.

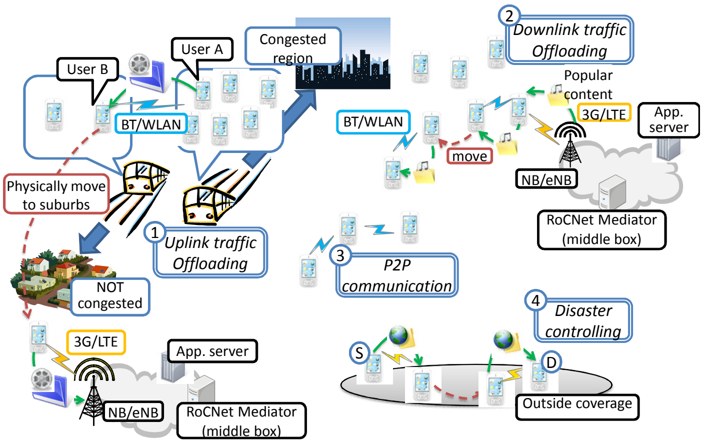


Figure 1. High-level Overview of RocNet

3. RoCNet: Robust Cellular Network for Disaster Communication and Traffic Offloading

In RoCNet, while the cellular network is used as both signaling and bearer channels, the store-carry-forward message switching mechanism via, e.g., the Bluetooth or the wireless LAN, which is used in DTN, is mainly used as bearer channel especially for non-real-time (or delay tolerant) application data when the cellular network is available. Since the message switching mechanism has some drawbacks such as message delivery delay and delivery rate, the cellular network is normally chosen as a communication path as far as the network is not congested. In other words, the degree of congestion in the cellular network decides a path of data-forwarding. When the cellular network becomes unavailable, the store-carry-forward message switching mechanism completely works along with information or knowledge that a user terminal obtained beforehand when the network was available. In the following, some situations where RoCNet works are briefly presented.

3.1. RoCNet uplink scenario

In the transmission direction from a user terminal to a BS (i.e., uplink), a message generated in the congested area can be forwarded to another terminal that is heading for non-congested area rather than directly transmitted to a BS in the congested area in order to offload the traffic. Then, the message would be carried followed by being transferred to a non-congested BS. For instance,

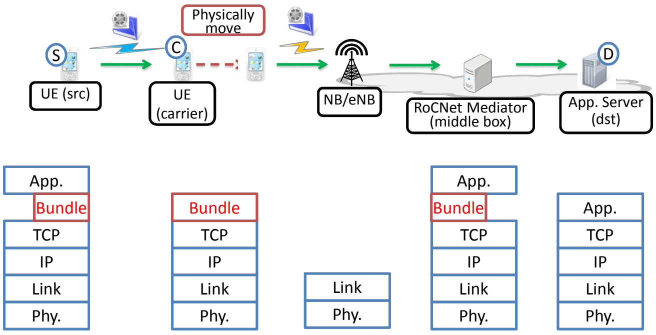


Figure 2. RocNet architecture

in Fig. 1, a non-real-time message originated by a user A who is commuting to a city center (congested business district) is forwarded to a user B who is traveling in the opposite way at a train platform. As the user B is approaching to a suburban area, the message is transferred to a BS. Note that a message (i.e., application data) can be divided into multiple pieces of data as in the DTN bundle protocol. To realize the scenario above with minimal impact to existing nodes, an architecture shown in Fig. 2 is introduced. The RoCNet architecture exploits the DTN bundle protocol, and introduces a middle box named the RoCNet mediator as a termination point of the bundle protocol. The divided data would be reconstructed to the original message in the RoCNet mediator followed by being forwarded to a destination.

3.2. RoCNet downlink scenario

In the transmission direction from a BS to a user terminal (i.e., downlink), a straightforward idea to offload traffic would be to facilitate an exchange of application data with high popularity among user terminals. The RoCNet mediator may assume a user terminal as an in-network cache point and control it to realize a local data distribution with a difference in the time of the data requests, which could be different from the existing studies described in section 2 which consistently focus on a data distribution from a server via a terminal.

In both RoCNet uplink and downlink scenarios, a delivery acknowledgement and a retransmission request could be done through the cellular network, which could easily and promptly improve the message delivery rate.

3.3. RoCNet P2P scenario

In the case of the P2P (Pear-to-Pear) communication such as a file exchange, the cellular network would become a control plane. Therefore, a user terminal could obtain routing-related information such as a physical location of a target terminal through the cellular network, which would enable data-forwarding in the opportunistic network as a bearer plane so that a more effective (i.e., lower overhead) data exchange can achieve.

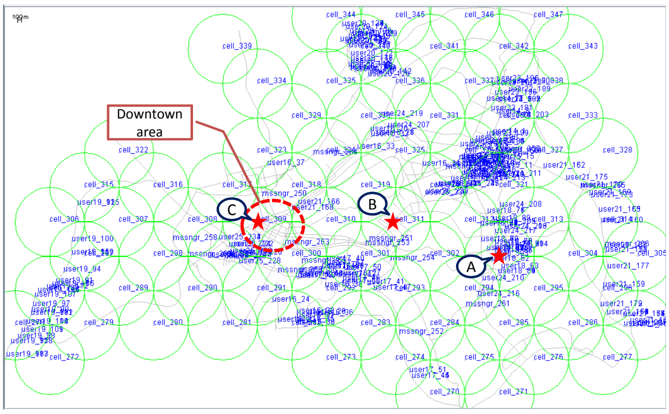
3.4. RoCNet disaster communication scenario

Even when the cellular network becomes unavailable, the store-carry-forward message switching mechanism could effectively work by using information or knowledge, such as a physical location of a target terminal, that a user terminal obtained beforehand when the network was available.

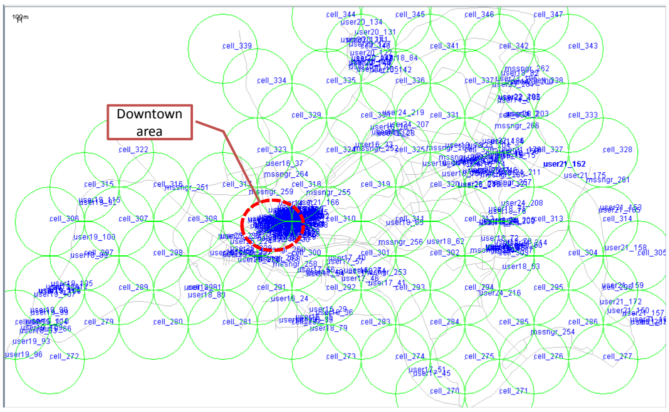
4. Proof of Concept

We have conducted a preliminary evaluation to investigate the performance of the RoCNet uplink transmission scenario. In this evaluation, we used the Opportunistic Network Environment (ONE) simulator [11] that is a computer simulator written in Java for evaluating DTN routing protocols, etc., under several user movement models.

In this evaluation, we focused on the effect of the traffic offloading by smoothing out traffic imbalances the store-carry-forward fashion gave. Figure 3 shows the simulation environment. In order to evaluate the performance in a realistic scenario as much as possible, we used the real-world moving pattern in which users moved around on a map of Pittsburgh, PA, USA., which was provided in [12]. In this simulation, we had 250 users (referred as user*xx_yy* in Fig. 3) on the map covering the area of 18.2 x 11.7 [km^2]. The ONE simulator provides us



(a) Users (user*xx_yy*) are at home in the morning; at the start of the simulation



(b) Most users (user*xx_yy*) are in their offices in the daytime; at the last of the simulation

Figure 3. Simulation environment overlaid on the real map around Pittsburgh (PA, USA); Solid circle represents coverage of a 3G BS (cell_*zz*), and a light gray line represents a load.

TABLE I: SIMULATION PARAMETERS

Parameters	Value	Remarks
Area size [km]	18.2 x 11.7	Around Pittsburgh (PA, USA)[12]
The number of user terminals	250	
The number of messengers	30, 50, 100	Data carrier
Radio coverage of 3G [m]	1000	
Radio coverage of Bluetooth [m]	100	Assuming class 1
Maximal transmission speed of 3G [Mbps]	21.6	Assuming HSUPA
Maximal transmission speed of Bluetooth [Mbps]	24	Assuming Bluetooth 3.0 +HS
Movement model	Working day movement (users) Shortest Path Map Based Movement (messengers)	
Moving speed [m/s]	2 - 5	Users
	4 - 10	Messengers
Wait time of messengers after reaching destination s	60 - 120	
Messages size [KB]	1 - 500	Randomly selected
Message generation interval [s]	1 - 60	Randomly selected
Storage capacity in each terminal [GB]	2	
Simulation time [sec]	7200	2 hours

several mobility models including Working Day Movement Model [13] in which the users go to work in the morning, spend their day moving inside their offices or having meetings, go shopping or walk around the streets after work, and finally commute back to their homes in the evening. We utilized this model, i.e., the users lived in residential areas around Pittsburgh and went to work in the morning to the business district located in the downtown of Pittsburgh. 3G cellular BSs whose coverage are represented as a circle in the figure were installed on the map to completely cover the residential areas, downtown areas, and loads where users passed. Users generated messages whose sizes were randomly selected from 1 KB to 500 KB in intervals that were randomly selected from 1 s to 60 s. The simulation time was 7200 s, i.e., two hours. Therefore, the simulation ended when the users were still working in their offices as shown in Fig. 3 (b). Other parameters are shown in Table I. Note that, in this evaluation, all messages assumed to be delay-tolerant, i.e., non-real-time data.

For comparison, we first conducted a simulation in a scenario, which we call 3G scenario here, where user terminals had one communication interface (3G interface), and only attached to a 3G BS to transmit messages. We then simulated RoCNet scenario in which user terminals were equipped with two interfaces: 3G and Bluetooth interfaces. In addition to the user who went along the Working Day Movement Model, a messenger who had a role in carrying messages was introduced in the RoCNet scenario. The messenger followed Shortest Path Map Based Movement (SPMBM) in which the DijKstra's shortest path algorithm was used to calculate a shortest route based on a map from current location to pre-defined points of interests (841 points in total in this evaluation). The SPMBM was also provided by the ONE simulator. The number of messengers varied; 30, 50, and 100. The messenger did not generate any messages by themselves but just received messages from user terminals, carried them, and forwarded to BSs.

The user terminals directly transmitted a message to a BS whenever the BS was not congested. In this simulation, a BS that had more than 30 connections was considered to be under congestion. If there were a Bluetooth connection with a messenger when the current BS was congested, the terminal forwarded a message to the messenger rather than directly transmitted it to the BS that was under congestion. Otherwise, i.e., if there was no available Bluetooth connection, the terminal sent a message to the current BS. A messenger who received a message from a user terminal forwarded it to the BS that was not congested after carrying it.

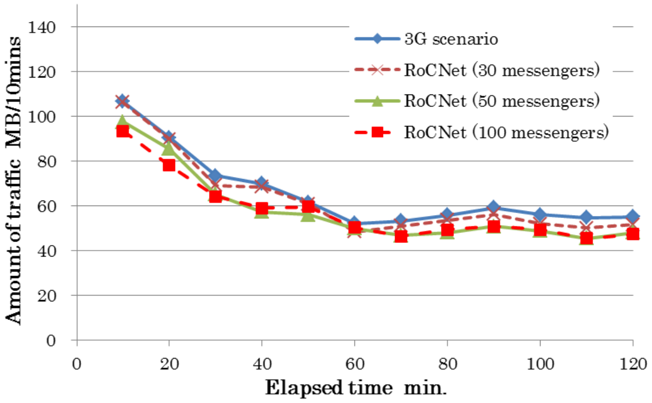
Figure 4 shows transitions of traffic in the BSs A, B, and C shown in Fig. 3 (a). In BS-A that was installed in a residential district, the amount of traffic treated in the BS-A decreased with time as shown in Fig. 4 (a) since some users gradually went to work. In BS-B whose coverage included one of commute routes, the amount of traffic treated by the BS-B increased only while users commuted as shown in Fig. 4 (b). Since both BSs A and B were not so congested, there are not clear differences between 3G and RoCNet scenarios as shown in Figs. 4 (a) and (b).

On the other hand, in the BS-C that was in the business district, the amount of traffic increased up to around 390 MB/10mins, which means the BS-C was heavily congested, in the 3G scenario as shown in Fig. 4 (c). We found that, in the RoCNet scenario, traffic load drastically reduced owing to the store-carry-forward message switching mechanism in the high traffic demand time zones (i.e., 50 minutes after the start of the simulation). The RoCNet scenario with 100 messengers reduced almost by half the traffic concentration in the BS-C. While the delivery ratios were the same among all scenarios, the average delivery latencies were different: about 0.8 s in the 3G scenario, and about 10 s in the RoCNet scenario due to the store-carry-forward message switching mechanism.

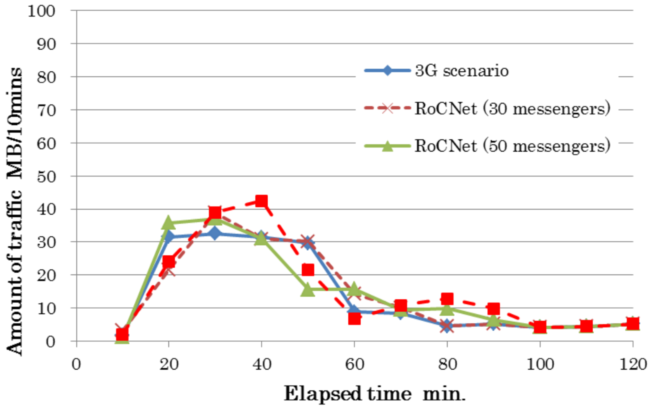
5. Conclusion

In this paper, we proposed a robust cellular network (RoCNet) that combines infrastructure-based and opportunistic networking for disaster controlling and data offloading, and presented the overview of RoCNet. We also gave four RoCNet scenarios; uplink traffic offloading, downlink traffic offloading, P2P communication, and disaster communication scenarios. We simulated the uplink traffic offloading scenario using the realistic user movement model and Pittsburgh map as a proof-of-concept work. The result indicated that RoCNet can alleviate the traffic congestion through the store-carry-forward message switching mechanism that only worked when a current BS to which a user terminal is connected was under congestion.

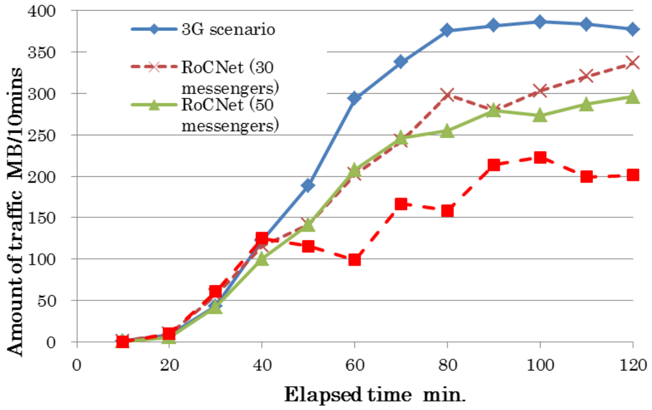
As our future study, we will further consider the RoCNet mechanism, especially downlink traffic offloading mechanism, in more detail. In addition, as an evaluation environment, we will prepare the map of Tokyo in order to simulate RoCNet in more realistic scenario.



(a) Amount of data in the BS A



(b) Amount of data in the BS B



(c) Amount of data in the BS C

Figure 4. Transition of traffic in each BS

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