Low Power Consumption Mobile Ad Hoc Network System

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ABSTRACT

In order to solve the environmental crisis problem and to realize the sustainable environment, we need the efforts to reduce energy consumption. It is reported that the energy consumption by IT including communication will rapidly grow. Based on this situation, Japan Science and Technology Agency (JST) has begun the project of "Ultra low power consumption information technology" under the umbrella of the competitive research fund named "Core Research for Evolutional Science and Technology (CREST)". We have applied to the open call for proposal and our proposal "Ultra low power Data Driven Networking System (ULPDDNS)" has been accepted as one of 2007-2012 frame projects by JST CREST. Our objective is to develop a data-driven networking system that can achieve reduction of power consumption to 1/100-1/1000 compared with the existing systems, especially in the situation just after a disaster happened. We believe the most applicable network to disaster situation is Mobile Ad hoc NETwork (MANET). This paper introduces the ULPDDNS research activities mainly from the viewpoint of network, i.e., MANET and shows three techniques to establish highly efficient and energy saving MANETs with reasonable performance: (1) GPS-aided target information discovery, (2) Load-aware broadcast-type contents delivery, and (3) Trust relationship list based key management.

1. INTRODUCTION

Environmental crisis caused by such as global warming is crucially becoming realistic. In order to solve the problems and to realize the sustainable environment, we need the efforts from versatile viewpoints. So far, the use of IT including communication was the driving force of penetration of ecology; for example, remote teleconferencing instead of real travelling, electronic document instead of real paper, and so on. These can be called "Eco BY IT". Now, however, "Eco OF IT itself including communication systems" must be tackled urgently. It is because energy consumption of IT is growing rapidly. Taking the Internet as an example, research

reports [1][2] say it will consume five times more electric power than existing Internet within a few years. Ecology, especially, reduction of power consumption of communication systems must be a most important and urgent issue to tackle with. Bearing this situation in mind, Japan Science and Technology Agency (JST) [3] has begun the research activity "Ultra low power consumption information technology" [4] under the umbrella of the competitive research fund named "Core Research for Evolutional Science and Technology (CREST)" [5]. We have applied the open call for proposal. Through the severe competition, our proposal "Ultra Low Power Data Driven Networking System (ULPDDNS)" [6] has been accepted as one of 2007-2012 time frame projects by JST CREST.

The ULPDDNS consists of mainly two parts: one is the platform (processor) and the other is the network. Our objective is to develop a data-driven networking system that can achieve reduction of power consumption to 1/100-1/1000 compared with the existing systems, especially in the situation just after a disaster happens. This ULPDDNS research team consists of three players, University of Tsukuba [7], Kochi University of Technology [8] and Tokai University [9]. The former two parties are studying mainly the reduction of power consumption of the platform, that is, the processor which consists of chip multiprocessor with self timed processing capability. We, Tokai University, are tackling with the reduction of power consumption of the network portion.

We believe the most applicable network architecture to disaster situation is Mobile Ad hoc NETwork (MANET) [10][11]. A MANET is defined as a group of wireless devices that are capable of organizing themselves in a mesh topology in order to find routes and relay packets from each node to any other node within the network without a support of a pre-installed infrastructure. The deployment of these networks is expected to take place in critical environments such as during disaster or on battlefield, where pre-installed infrastructure is not available. We assume the network portion of ULPDDNS is to be MANET and have been studying MANET architecture that can achieve the high efficiency to reduce power consumption with keeping possibly high performance. In order to make both network efficiency and performance (QoS and security) better, we have to consider that emergency network has several network usage phases such as (1) network setting-up phase (just after a disaster happened), (2) stable

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phase.

This paper will show firstly the overview of "Ultra low power consumption information technology", CREST and its possible deployment to the real world and introduce a rough sketch of our ULPDDNS project. And then it will discuss Tokai activities, that is, three techniques to establish highly efficient MANETs with reasonable performance: (1) GPS-aided target information discovery, (2) Load-aware broadcast-type contents delivery, and (3) Trust relationship list based key management.

2. ULTRA LOW POWER CONSUMPTION INFORMATION TECHNOLOGY (CREST ULP)

2.1 CREST ULP

IT including telecommunication has provided virtue to us by saving time and cost, and has achieved energy saving. However, power consumed in IT systems themselves is growing rapidly year by year. Reports [1][2] say the ratio of electric power consumed by IT appliance to total produced power is about 6 % now but it will be 20% in 2020 (Fig. 1). It is crucially needed to consider the reduction of power consumption of IT, that is, eco of IT.
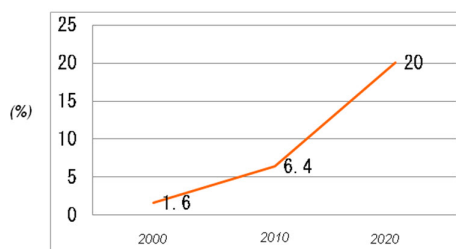
Electric power consumed by IT appliances / Total electric power produced

Fig.1: *Power consumption of IT*

Based on this situation, there are many ongoing research activities all over the world tackling with energy saving issues of IT systems. Among them, Japan Science and Technology Agency (JST) [3] made an open call for research proposal regarding the energy saving of IT. The call for proposal is named "Technology Innovation and Integration for Information Systems with Ultra Low Power (ULP) [4]." This activity is under the umbrella of a basic research program, "Core Research for Evolutional Science and Technology (CREST) [5]."

Since the economical growth in Base of the Pyramid (BoP) [12] is anticipated in coming decade and energy consumption in BoP area will increase rapidly, energy consumption issues will have to be solved urgently. Hence the general objective of CREST ULP is to enable sustainable growth by saving energy of IT to the utmost limit. CREST ULP activity consists of several project teams, which cover various layers

of IT systems such as circuits, devices, computer architecture, OS, algorithms, networks, etc. The challenging targets of CREST ULP are (1) Reduction of power consumption to 1/100 - 1/1000 compared with existing systems, and (2) Application to non-mature infrastructure environment (BoP area).

University of Tsukuba, Kochi University of Technology and Tokai University applied the CREST-ULP open call and were accepted as one of the research teams sharing the CREST-ULP. Our research project is named "Ultra-Low Power Consumption Data-Driven Networking System (ULPDDNS) [6]."

2.2 ULPDDNS overview

The objective of ULPDDNS is to realize an ultra-low-power data-driven networking system based on not only ad-hoc networking scheme and platform technology using data-driven chip multi processor realized by self-timed elastic pipeline but also an organic integration of them, by exhaustively exploiting passive data-driven principle with essential affinity for communication processing. Our ULPDDNS aims at developing the ULP data-driven networking system by which the coming networking environment can be achieved with ultra-low-power consumption: 1/100 to 1/1000 of the present.

Main study issues are realizing (1) Platform built by data-driven chip multi-processor using self-timed elastic pipeline and (2) Networking system based on mobile ad hoc network (MANET). Research team is grouped into two sub teams, that is, platform team and network team [13][14]. The platform team consists of University of Tsukuba and Kochi University of Technology and tackles with platform (Processor) and the network team is Tokai University tackling with MANET. Research period is from October 2007 to March 2013 (5.5 years) and the total research fund is ¥418,620,800.

3. MANET STUDIES IN ULPDDNS

3.1 Applicability of MANET to the disaster situation

From here, overview of research activities on network sub team of ULPDDNS is introduced. As shown above, network team is tackling with MANET as a target network. MANET has no infrastructure, no centralized controllability, dynamically changing network topology, and multi-hop information transmission (Fig. 2). It is an infrastructure-less and a group of wireless and mobile devices that organize themselves, can be an alternative to the existing network infrastructure in case of emergency and/or events, consumes less power in nature than existing infrastructure, and will play an important role for achieving low power consumption network.

Our target is reduction of "number of packets" for mainly "control/management messages" to 1/10 of
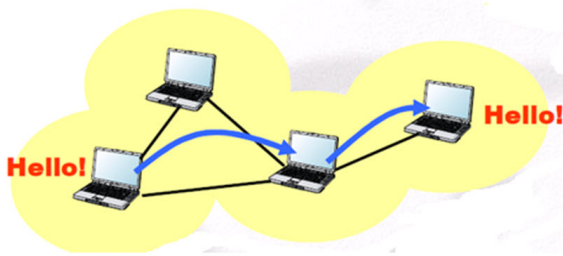
Fig.2: *Mobile Ad hoc Network (MANET)*

the present in case of emergency (just after disaster happens). MANET is most applicable to the disaster situation and the situation needs ultra low power consumption to make battery have longer life time.

After the disaster, we have to consider network life time. We consider following two phases.

- Phase 1 (transient)

This phase means that of just after the disaster happened. Several nodes in some area may organize a MANET but each node may not know IDs of other nodes such as IP addresses. So, usual routing (unicast or multicast data transfer) cannot be executed. In this phase, however, useful information must be sent all over the network urgently such as "where is a refuge, hospital?", "how is my house?", and so on. Both "Pull" (Information discovering) and "Push" (Information broadcasting) are needed without use of IP addresses.

- Phase 2 (stable)

In this phase, each node has each routing table and the network becomes stable. Usual communication based on routing with possibly high QoS and security will be required. We have clarified main three study issues in association with two phases above after MANET setting up.

As for phase 1, "effective information discovery" without IP addresses is needed because people in the network, just after the disaster, would probably need such information as refuges, hospitals, and his own house. For this purpose, we have proposed "a GPS based discovery mechanism" [15][16] with reduced control packets. For phase 1, "Effective data transfer" is also needed because people who have some useful information would like to let as many people as possible know the information without IP addresses. For this purpose, we have proposed "Load-aware flooding". This flooding needs no IP address and can reduce redundant packets. Of course the flooding can be used in phase 2 also.

As for phase 2, networks become stable and usual communication by use of IP addresses will be executed. In some cases, "effective secure communication" with ciphering will be needed. For this purpose, we have proposed "Self-organized key management based on trust relationship list"

3.2 Effective information discovery

In case of an emergency phase 1 (just after the disaster happens), local information is probably needed. For instance, for people in the MANET, information about refuges, hospitals and their own houses is urgently needed. This fact requires some information or contents discovery mechanism. Those who need such information would like to inquire other people in the MANET about the information. However, in phase 1, there are some constraints, one of which is that each node address is not well known to other nodes and usual routing based communication (unicasting and multicasting) is unavailable to use. In this situation, only available way of inquiry is using "Simple Flooding (SF)." The SF mechanism is as follows: Simple Flooding is used to deliver messages to the whole network. A node that originates a packet broadcasts it. The packet reaches all the nodes that exist within the area covered by the radio wave transmitted by the origin node. A node that has received the packet re-broadcasts it. This process is repeated by subsequent nodes until the packet reaches all the nodes in the network. In the information discovery, a node sends an inquiry packet to the whole nodes using SF. But, multiplication and contention of inquiry packets will occur and result in waste of electric power. Hence, Effective information discovery with reducing wasteful inquiry packets is needed.

We have proposed a discovery method, which uses location coordinates of nodes using Global Positioning System (GPS), and successive queries and replies between adjacent nodes [15][16]. This method assumes that (i) a node inquiring information (start node) knows the location of destination of which the starting node needs information, for example by use of a map, (ii) some node in the neighbor area of the destination may have the information about the destination which itself is not a ad hoc node, and (iii) each node has GPS terminal. Fig.3 shows a rough sketch of our proposed procedure. To prevent the widespread diffusion of messages in the network which is the major problem with SF, the proposed method uses the location information so that reply packets are sent in response to queries only which have been sent in the pre-defined reply area (hatched area in Fig. 3) direction of the destination. By the computer simulation, it is clarified that this method reduces to 25% of simple flooding in best case both the number of packets transmitted/received and the power consumed in the entire network (Fig. 4), and showed power needed to GPS operation is negligible.

3.3 Effective data transfer

In emergency situation (phase 1), a number of specific nodes may send urgent audio or video messages, such as evacuation instructions for disaster victims or instructions for rescue teams, to the entire network at a high bit rate without using any routing proto-
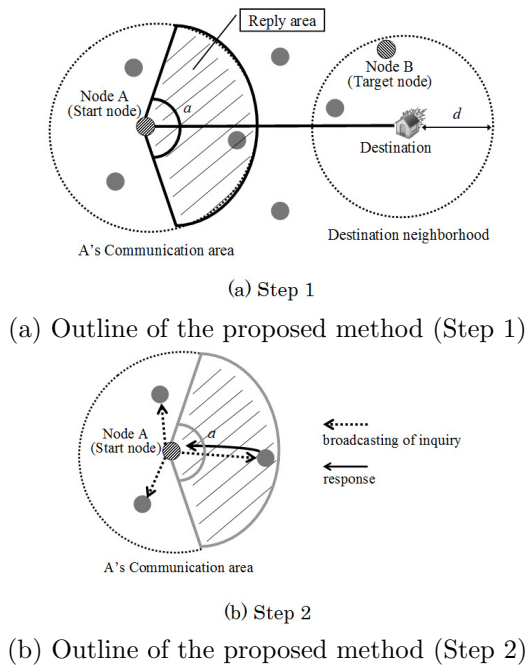
(a) Step 1

(a) Outline of the proposed method (Step 1)

(b) Step 2

(b) Outline of the proposed method (Step 2)

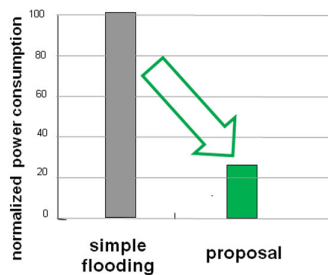**Fig.3:** *Outline of the GPS based discovery mechanism*

Fig.4: *Effect of GPS based discovery*

col. Flooding is the only delivery method to achieve this. However, as described in 3.2, conventional SF is not well suited for this purpose because it results in broadcasting too many unnecessary packets, which increases the chance of data collisions and buffer overflows, resulting in an increase in packet loss. Nodes in an ad hoc network are generally powered by batteries with a finite capacity and so reducing power consumption is an important issue. Since the transmission of redundant packets accelerates the consumption of battery power, an effective network protocol-based solution to reducing power consumption is to reduce the transmission of redundant packets.

Hence, we have proposed an effective data broadcasting, "Load-aware flooding" [17][18][19]. Our method uses the number of packets waiting for transmission in the MAC output queue of each node to obtain neighboring load information without periodical transmission of Hello messages. The reason why our method uses the number of packets in the queue is that at the time when the packets are existing in

a node's queue, the node is going to transmit frames exceeding its link capacity. If the node rebroadcasts a message in this situation, frame loss and collision due to buffer overflow are likely to happen. Therefore, the number of packets in the queue is useful information to recognize the load conditions without any status informing packet transmission.

By the computer simulation, it is clarified that this method reduces to 25% of simple flooding in best case both the number of packets transmitted/received and the power consumed in the entire network (Fig. 5). Our method also increases packets reachability from 71% to 99.9%, which means most of packets penetrates all over the network (Fig.5).
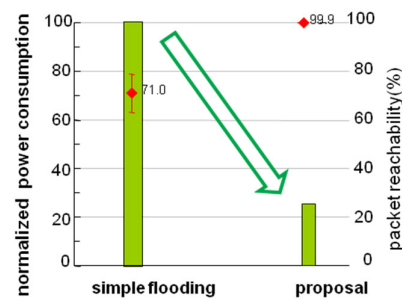

Fig.5: *Effect of Load-aware Flooding*

3.4 Effective secure communication

After contents discovery and routing table construction, the network enters stable phase 2. In phase 2, secure communication may be needed also in the MANET. The main problem of any public key based security system is to make each user's public key available to others in such a way that its authenticity is verifiable. In mobile ad hoc networks, this problem becomes even more difficult to solve because of the absence of centralized services, and possible network partitions. More precisely, two users willing to authenticate each other are likely to have access only to a subset of nodes of the network. The best known approach to the public key management problem is based on PKI (public Key Infrastructure) [20]. A public key certificate is a data structure in which a public key is bound to an identity by the digital signature of the issuer of the certificate. However, in a MANET without any infrastructure support, most traditional solutions are not directly applicable. The goal of our research is to understand the specific challenges for providing key management in MANETs and use this understanding to design an effective key management framework.

We, for the purpose, proposed a Trust Relationship based Self-Organizing Key Management system [21][22] that allows users to create, store, distribute, and revoke their public keys without the help of any trusted authority or fixed server. Web-of-Trust fits naturally with MANETs, relying on each mobile node

to issue certificates to other nodes at their own discretion [23]. This approach, however, suffers from frequent communication and much memory spaces because it must collect all the public key certificates beforehand. In order to resolve this defect, our approach, instead of collecting certificates themselves, generates and modifies "trust relationship lists" describing the trust relationship only without certificates among users.

By computer simulation, our proposal drastically reduces number of packets (1/100 to the existing method) (Fig.6).
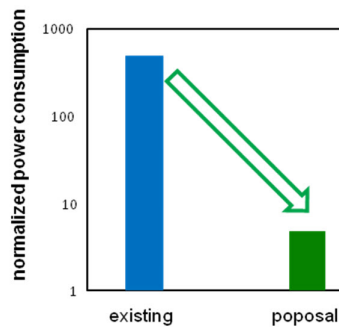

Fig.6: *Trust Relationship based Self-Organizing Key Management*

4. CONCLUSION

As one of JST CREST ULP research projects, our ULPDDNS are tackling with reducing power consumption of communication systems to 1/1000 compared with existing systems. Main contribution is energy saving in the platform based on Data-driven processor and the network based on MANET. This paper described the network portion contribution in ULPDDNS. After the disaster, this paper introduced three main activities on MANET energy saving mechanisms as information discovery, information broadcasting, and authentication, and showed their high effectiveness. To realize system and show the actual effectiveness (power saving effect) specifically, we plan to use one more year to synthesize all the activities of ULPDDNS. It will probably contribute to achieving Echo of IT specifically.

5. ACKNOWLEDGEMENT

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