WBAN meets WBAN: Smart Mobile Space over Wireless Body Area Networks

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***Abstract*—A wireless body area network (WBAN) has recently issued a next generation wireless technology of wireless personal area networks (WPAN) and it will provide various ubiquitous services for both medical and non-medical services. In addition, when WBANs are intelligently interworked, more smart services will be available. Although the current IEEE 802.15.6 standard recognizes only an individually organized WBAN, they should be integrated to perform large-scale services. To support the interworking of WBANs, a new network architecture and its maintenance scheme are required. In this paper, we propose a novel network architecture for supporting data routing in an individual WBAN as well as combining and splitting individual WBANs for large-scale WBAN services.**

I. Introduction

Recent advances in WPAN technology have evolved to provide various services, with healthcare being the most frequently provided service. However, existing WPANs have not evolved enough to provide various smart services because, so far, they have only been designed for medical healthcare information. In general, medical applications include monitoring of biomedical signals, and low rate remote control of medical devices. Non-medical applications include audio, video, and bulk data transfer, etc. The smart services should provide flexible services among medical and non-medical devices.

A WBAN, which is a type of WPANs, functions in the vicinity of, on, or inside a human body. It consists of a coordinator, medical devices and non-medical devices. Recently, IEEE adopted the WBAN as the next generation of wireless technology for WPANs and the WBAN starts as a task group (TG) of WPANs from November, 2007 [1], [2], [3]. A WBAN will mainly be utilized for smart services, including healthcare, and it allows simultaneously both medical and non-medical applications. In addition, a WBAN provides a flexible data rate of 10Kbps to 10Mbps as well as a very short transmission range of at least 3m with low power. Because of these characteristics, a WBAN is distinguished from existing WPAN technologies, and thus, a novel network architecture for WBAN smart services is indispensable.

Until now, monitoring of the human body has been the key technology for WBAN smart services [4], [5], [6]. There are several projects about the u-Healthcare services such as MobiHealth [7], M-health [8], Personal Care Connect [9] and CareNet [10]. These projects collect and analyze medical information from the human body. The projects were developed based on WPAN technologies. Specifically, they only dealt with medical information over networks, but could not consider a network of WBANs.

Although the current IEEE 802.15.6 treats only individually organized WBAN on or in a person, it can be integrated within large-scale services. Specifically, several individual WBANs are combined into a network of WBANs and some individual WBANs are separated from the network in a public area because individual persons move around the service area. When a WBAN meets other WBANs, a network of WBANs may be constructed and additional smart services may be provided on the network via the intelligent interworking of WBANs. A smart mobile space is defined as a service area constructed by a network of WBANs. In order to support this scenario, a proper network architecture and its maintenance scheme are required. In this paper, we propose a novel network architecture for supporting both data routing in an individual WBAN as well as combining and splitting individual WBANs for large-scale WBAN services.

II. Related work

IEEE 802.15.6 is the WBAN standard and it aims to support the following design aspects: a low complexity, low cost, low power and reliable transmission. It has three types of applications [1], [2]: healthcare, assistance to people with disabilities, and entertainment. Additionally, people may utilize these applications simultaneously. Traffic flow can vary depending on the following applications: point-to-multipoint, multipoint-to-point, and point-to-point. IEEE 802.15.6 allows a 5% packet error rate and a 256 byte payload at very short transmission range with a flexible data rate. It also adopts four channel models among the WBAN devices. In addition, it considers two PHYs to be MICS and ISM and supports the periodic traffic and burst traffic for various applications. For Quality of Service (QoS), the latency in medical applications should be less than 125ms and the latency in non-medical applications should be less than 250ms [3].

The network architectures for the existing WBAN projects are constructed as a two-tier wireless network [7], [8], [9], [10]. The lower tier contains several sensor devices connected to a coordinator and ZigBee or Bluetooth is used for the data transmission. At the higher tier, the coordinator connects with an Internet gateway and wireless local area network (WLAN) or wireless wide area network (WWAN) technology is utilized to communicate with the coordinator with an external server

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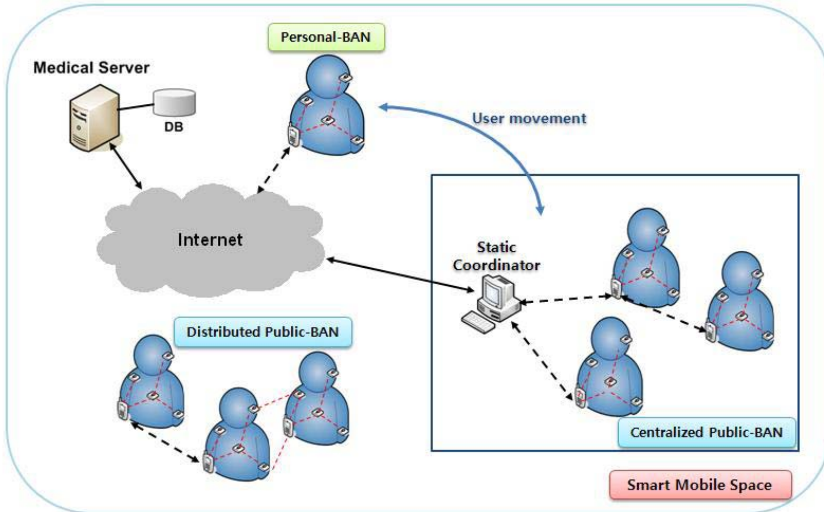

Fig. 1. An architecture of a smart mobile space.

via the Internet. The existing network architectures focus on the status monitoring of an individual WBAN. Thus, sensor devices over network architectures transmit medical information with a low data rate. However, as mentioned previously, WBAN should provide flexible services in both medical and non-medical devices and should be integrated for large-scale services. Thus, since the existing network architectures do not satisfy the requirements for WBAN, a novel network architecture for WBAN smart services is indispensable.

III. An Architecture of a Smart Mobile Space

In a smart mobile space, various WBAN services can exist and we can define a personal-BAN as a conventional WBAN and a public-BAN as a network of several personal-BANs as shown in Fig. 1. A personal-BAN consists of a portable coordinator, medical devices, and non-medical devices. A portable coordinator collects medical information, controls devices and connects to external networks. A public-BAN is divided into a centralized public-BAN and a distributed public-BAN. A static coordinator exists in a centralized public-BAN and is connected with portable coordinators of several personal-BANs. The static coordinator is able to command a portable coordinator in order to control a personal-BAN and runs as an Internet gateway. In a distributed public-BAN, data transmission among personal-BANs is performed without a static coordinator.

There are three types of communication: a personal-BAN allows a portable coordinator to communicate with both medical and non-medical devices. A personal-BAN can also communicate with other personal-BANs in a centralized public-BAN or a distributed public-BAN.

A. Personal-BAN

IEEE 802.15.6 defines the following elements that should be present for an individual BAN: a coordinator, medical devices, and non-medical devices. As shown in Fig. 2, a personal-BAN has the same elements as shown in IEEE 802.15.6. In a personal-BAN, the devices are managed by a portable coordinator and the device data is forwarded to the coordinator. The personal-BAN focuses on both medical and non-medical data transmission with a combination of low complexity and ultra-low power. In general, data transmissions for medical devices are considered to be of a low rate and periodic in nature. On the other hand, non-medical devices are entertainment devices which require a high rate and they commonly used for event-driven applications. To route both medical and non-medical data, we apply the concept of Lowest Weight Routing (LWR) [11] to a WBAN, which is our energy aware method for constructing a routing table in wireless sensor networks.

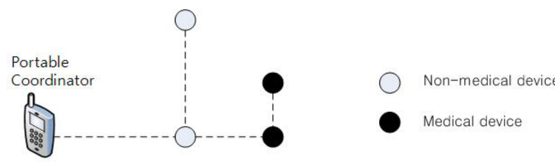

Fig. 2. A Personal-BAN.

In the proposed scheme, a portable coordinator broadcasts a control message for constructing or updating a device's routing in a personal-BAN. A device receiving this message computes its weight and then forwards the message containing the weight and device type (i.e., medical or non-medical) to its neighbors. The weight f_w is calculated via the following utility function consisting of a signal level (l) depicted by an integer, hop counts (h) from a portable coordinator and residual energy ratio (e) of a device:

$$f_w = \frac{l \cdot h}{e\ (\%)} + f_u, \qquad (1)$$

where f_u is the weight from the previous node u. When a

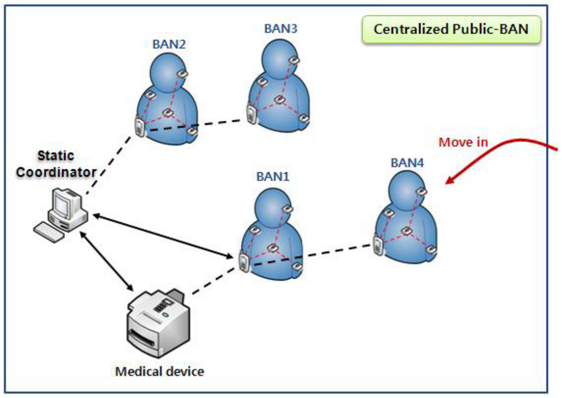

Fig. 3. A Centralized Public-BAN.

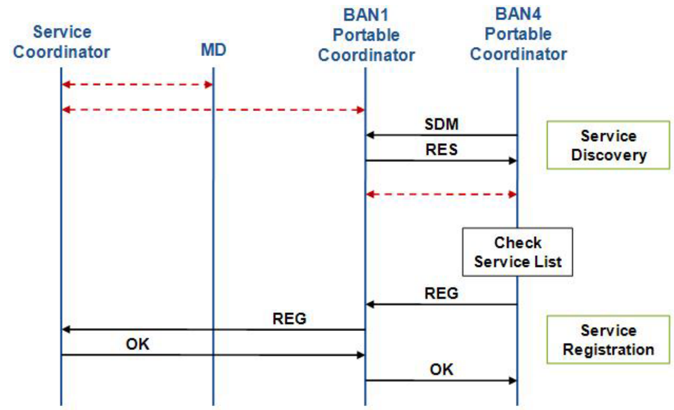

Fig. 4. The Service Discovery and Registration.

device receives the messages from its neighbors, it constructs a routing table from the message information (i.e., device id, weight, and device type).

Each device in a personal-BAN selects the device with the lowest weight among neighbors in a routing table as the next hop but devices with non-medical traffic should not choose medical devices as the next hop because non-medical devices differ from medical devices (i.e., data rate and application characteristic). Only the devices with medical traffic can choose both medical and non-medical devices as a next hop. Therefore, a device selects its next hop by using both the device type and weight.

B. Public-BAN

1) Centralized Public-BAN: A centralized public-BAN consists of a static coordinator and several personal-BANs. The public-BAN is a smart mobile space and it has either star or mesh topology centered on a static coordinator. In this place, the combining and splitting of personal-BANs may occur frequently. When a personal-BAN joins a centralized public-BAN, the combining of personal-BANs occurs. On the contrary, when a personal-BAN leaves a centralized public-BAN, the splitting of personal-BANs will occur.

Fig. 3 shows an example of a centralized public-BAN. Dotted lines indicate routing paths and arrow lines represent service sessions. Portable coordinators of personal-BANs construct an ad-hoc network and transmit data through a multi-hop. When a BAN4 moves into a centralized public-BAN, a BAN4 portable coordinator searches all the available services of a static coordinator or other portable coordinators by broadcasting a service discovery message (SDM). Coordinators receiving the SDM send a response message (RES) which contains their service information to the portable coordinator, which broadcasts a SDM. Fig. 3 shows that BAN4 found BAN1 and reconstructs its service list from the BAN1's RES. The service discovery is performed periodically in order to update the service list. The service list is also used for multi-hop data routing of portable coordinators and it includes the followings: ID (Identification of BAN, Static coordinator (SC), External medical device (MD) - the ID field distinguishes indirect elements from direct elements using colon), TYPE (Direct or Indirect service - Inner BAN services are direct services otherwise indirect services), PER (Permission to attach), DESC (Description of available services - SC indicates BAN IDs together using colon). Table I represents the service list of BAN4 after the service discovery. BAN4 has game as its own service and it does not use BAN1's direct or indirect services because BAN4 has no permission for the BAN1's services.

TABLE I
THE SERVICE LIST OF BAN4 AFTER THE SERVICE DISCOVERY.

ID	TYPE	PER	DESC
B4:B4	Direct	Yes	Game
B1:B1	Direct	No	Audio
B1:SC	Indirect	No	Diagnosis:SC, Medical:MD, Audio:B1
B1:MD	Indirect	No	Medical

Since the static coordinator is the manager of the centralized public-BAN, an incoming personal-BAN can provide various services by registering it with the static coordinator. Thus, after checking the service list, a portable coordinator of BAN4 sends a registration message (REG) to the static coordinator, which, at the service discovery phase, is found as an indirect service of BAN1. If a static coordinator responds as an OK message, then the PER field for the static coordinator of the service list becomes 'Yes' and BAN4 can then request the services of the static coordinator. Fig. 4 shows the call-flow of the service discovery and registration and Table II represents the service list of BAN4 following the service registration.

When a personal-BAN needs to access other networks (i.e., another personal-BAN or an external medical device) in order

TABLE II
THE SERVICE LIST OF BAN4 AFTER THE SERVICE REGISTRATION.

ID	TYPE	PER	DESC
B4:B4	Direct	Yes	Game
B1:B1	Direct	No	Audio
B1:SC	Indirect	Yes	Diagnosis:SC, Medical:MD, Audio:B1
B1:MD	Indirect	No	Medical

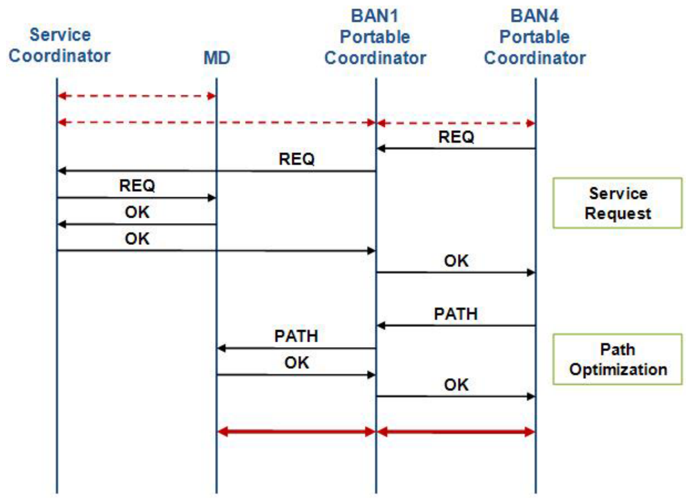

Fig. 5. The Service Request and Path Optimization.

TABLE III
THE SERVICE LIST OF BAN4 AFTER THE SERVICE REQUEST.

ID	TYPE	PER	DESC
B4:B4	Direct	Yes	Game
B1:B1	Direct	No	Audio
B1:SC	Indirect	Yes	Diagnosis:SC, Medical:MD, Audio:B1
B1:MD	Indirect	Yes	Medical

to receive their services, a request message (REQ) is sent from its portable coordinator. The REQ is then routed to a network with permission (i.e., a portable coordinator finds the service in DESC field of the service list and selects its next hop by referencing to the ID and PER field of the service list). Because a personal-BAN does not initially have access permission to other networks, it sends a REQ to a static coordinator. The static coordinator then forwards the message to the target network with the required service. As shown in Fig. 3, when BAN4 needs to attach to MD, it sends a REQ to the MD via BAN1's coordinator and the static coordinator. If BAN4's coordinator receives an OK message as the response from the MD, then the service list of BAN4 is modified as shown in Table III and the BAN4's coordinator performs a path optimization in order to find the most efficient path towards the MD.

In the path optimization phase, a PATH message from the BAN4's coordinator is forwarded along the REQ's path. At each relay node, a coordinator receiving the message searches within its service list. If it finds a target network for the BAN4 request service, the PATH message is forwarded to the target network by modifying the path. Then, by receiving the OK message through the optimized path, a service session between MD and BAN4 is created. Fig. 5 shows the call-flow. After creating a service session, portable coordinators perform service-aware routing which references the established paths at the path optimization phase. If a personal-BAN moves, a BAN portable coordinator performs a path optimization in order to keep the service session.

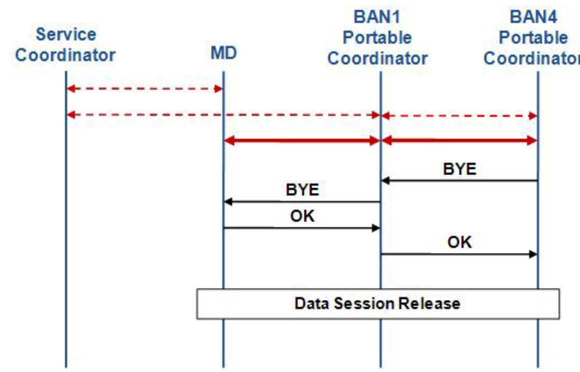

Fig. 6. The Service Release.

TABLE IV
THE SERVICE LIST OF BAN4 AFTER THE SERVICE RELEASE.

ID	TYPE	PER	DESC
B4:B4	Direct	Yes	Game
B1:B1	Direct	No	Audio
B1:SC	Indirect	Yes	Diagnosis:SC, Medical:MD, Audio:B1
B1:MD	Indirect	No	Medical

When a personal-BAN departs from a centralized public-BAN, a BAN portable coordinator sends a BYE message in order to release the service session. After a session release, the portable coordinator loses permission to access a target network. Fig. 6 shows the call-flow of the service release and Table IV represents the service list of the BAN4 after the service release phase.

2) Distributed Public-BAN: A distributed public-BAN is constructed without a static coordinator. Although a personal-BAN is not able to access a static coordinator, it can request other personal-BANs' services found at the service discovery phase. In the case of a distributed public-BAN, application services may occur among close personal-BANs. Specifically, a personal-BAN requests the services of a close personal-BAN coordinator or devices of a neighbor personal-BAN.

As shown in Fig. 7, when BAN4 joins a distributed public-BAN as a new personal-BAN, it performs the service discovery with the purpose of organizing a service list. BAN4 finds BAN2 via the procedure. BAN2 is already connected to BAN1. BAN4 can search several services already provided by its neighbor BANs from the service list. If BAN4 wants to use BAN1's services, which are considered indirect services of BAN2, it sends a REQ to BAN1 via BAN2. After the service request is sent, a path optimization is performed and a service session is created. Fig. 8 shows the call-flow of the service request in a distributed public-BAN. The creation or release of a data session is performed in the same manner, regardless of a static coordinator.

If a personal-BAN wants to control inner devices of personal-BAN neighbors, the portable coordinators of target BANs, which received the REQ, broadcast the BAN ID (BID) of an access BAN. Then the devices with the same BID between the access BAN and the target BANs are able to

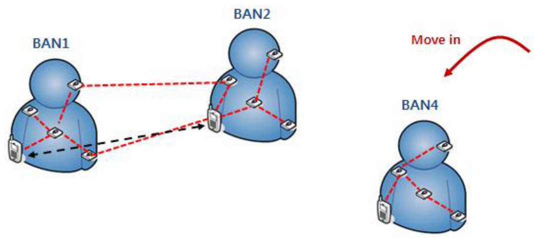

Fig. 7. A Distributed Public-BAN.

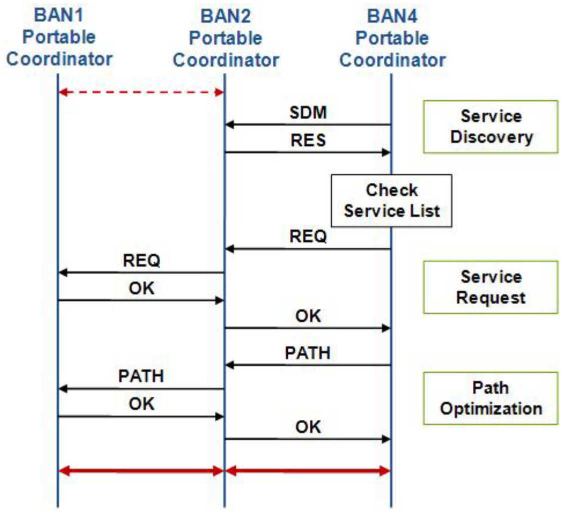

Fig. 8. Service Session Creation in a distributed public-BAN.

receive a control message from a coordinator of the access BAN in order to rebuild BAN topology. After the reorganization, the target BANs fuse into the access BAN and target BAN devices receive commands from the access BAN and can send their data. Fig. 9 shows the call-flow of the service request for inner BAN devices. When a personal-BAN leaves a distributed public-BAN, it sends a BYE and a portable coordinator receiving the BYE notices a session release to its inner devices. When a service session release occurs, the target BAN's devices remove the BID of the access BAN and the inner devices are not able to communicate with the access BAN.

IV. Conclusion

A wireless body area network (WBAN) deals with network services within personal areas. A smart mobile space, constructed by several WBANs, can provide flexible ubiquitous applications for people. In this paper, we have proposed a novel network architecture for the smart mobile space. A personal-BAN, used as an individual WBAN, is the smallest available element for the space and several personal-BANs compose a public-BAN. With the public-BAN, we can extend existing WBAN services and create new services. For the smart mobile space, the new network architecture provides both individual personal-BAN routing and a BAN combining / splitting technique for the public-BANs.

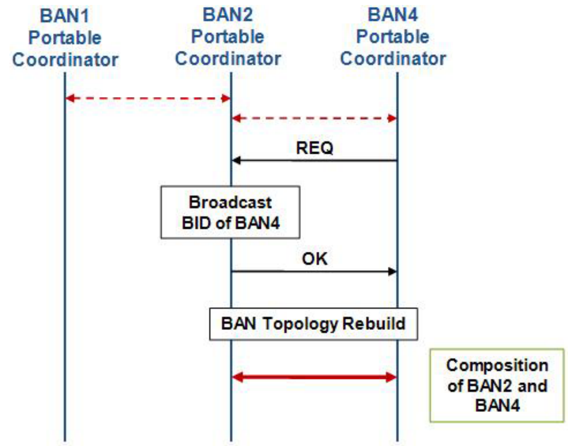

Fig. 9. The Service Request for inner BAN devices.

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