Development of Visualization and Performance Evaluation Testbed for Wireless Body Area Network

Aung Aung Phyo Wai, Wei Ni, Robert Hsieh and Yu Ge
Networking Protocols Department, Institute for Infocomm Research
1 Fusionopolis Way #21-01 Connexis
Singapore 138632
{apwaung, wni, rchsieh, geyu}@i2r.a-star.edu.sg

Abstract—**Due to the advances made in sensing, computing and networking, continuous monitoring and just-in-time prevention through Wireless Body Area Network (WBAN) in healthcare becomes a promising approach. In order to support healthcare needs, WBAN must achieve reliable data delivery and efficient resource management. To develop such healthcare solutions, understanding of system operations and performance evaluation in realistic settings beforehand will be an essential step. The main requirement is to visualize detailed node states and protocol operations considering RF channel characteristics around the body and their correlation on dynamic body postures. In this paper, we present the design and development of a testbed for WBAN that supports visualization of network operations as well as evaluation of system performance. We also identify challenges and requirements for developing WBAN healthcare applications. Then, we explain the system architecture and implementation as well as the experiment design and scenarios related to the proposed testbed.**

Keywords- visualization; performance evaluation; wireless body area network; testbe; healthcare applications)

I. INTRODUCTION

The proliferation of pervasive sensing, autonomous computing and wireless communication technologies empowers anywhere, anytime and seamless management of everyone's health and well-being [1]. In these pervasive healthcare paradigms [1], small, battery powered and wireless nodes are commonly employed in ambient, wearable and implantable settings to monitor from physical activities to physiological parameters [2]. Due to its potential continuous and personalized monitoring capability, healthcare applications using Wireless Body Area Network (WBAN), by attaching wearable sensor and wireless platform to the human body, play active research issues in scientific and medical communities. The WBAN healthcare applications can not only be applicable to monitoring continuous activities of the elderly but also to observing well-being of the healthy adults [2].

Although WBAN has such huge potentials and interests to revolutionize traditional healthcare [4], it still has several challenging issues in practical usage such as enhancing data reliability, reducing complexity and managing resource efficiently, etc as time and life critical applications are its primary usage. Unlike technical challenges like scalability and self-healing in ambient sensor network, WBAN has its unique challenges and limitations as only a few WBAN nodes are attached directly to the human body [2, 3]. For WBAN, reliability and resource management is not only important to enhance performance and prolong its life time but is also important to the health of subjects as they are wearing them on their body continuously around the clock [5]. Several recent works studied both network architectures and reliability issues related to WBAN usage in ambulatory healthcare monitoring applications [5, 13]. But there are still limited works on issues related to RF characterization [3] of WBAN around the body as well as real-life WBAN system performance evaluation [12] considering changing body movements and positions of the subject. Moreover, there is still lacking in user-friendly and efficient visualization of WBAN operations to examine the important parameters and configurations in realistic conditions.

In general sensor network applications, visualization is only considered as effective representation of densely scattered sensing data reported by large-scale network deployment [6]. Their main aim is to observe dynamic network topology, manage network operations and visualize heterogeneous data according to application specific requirements [7-11]. Unlike them, WBAN has salient requirements for visualizing real-time network information such as topology, protocols operation, wireless characteristics and system reliability [3]. Visualization tools like SpyGlass [10] and NetViewer [11] aimed to provide general visualization features targeted for rendering sensor data on top of underlying basic network information. Also, Octopus [8], MoteView [9] and NetTopo [7] targeted only to provide an extensible platform for monitoring, managing and visualizing network status without considering performance evaluation. None of existing works do not meet both visualization and performance evaluation requirements for testing various WBAN systems and applications. So we intend to implement a testbed for WBAN that can efficiently visualize underlying network protocols, network states and dynamic body postures. Our testbed is also designed to evaluate underlying WBAN performance through Radio Frequency (RF) channel models measurements and validation of the proposed reliability enhancement and resource management schemes.

The goal of this paper is to present the design and development of a testbed for visualization and performance evaluation of WBAN healthcare applications. In section II, specific technical challenges faced with WBAN in healthcare as well as architecture and features of proposed testbed will be explained. The technical requirements and implementation details will be discussed in section III. Finally, we conclude our testbed goals with possible future works and development trends in section IV and V respectively.

II. TECHNICAL CHALLENGES AND TESTBED DESIGN

A. Challenges in WBAN Healthcare Applications

The possible healthcare applications with WBAN can range from motions recognition and activity observations such as fall detection, gait analysis, etc. to ambulatory and physiological parameters monitoring [2]. Generally, the presence of antenna closest to the human body and movement artifacts affect network connectivity and wireless performance. So network performance evaluation with software simulation alone [12] or general network testbed does not reflect actual network operations and performance of WBAN system [4, 5]. Because reliability and performance of WBAN are highly affected by time-varying dynamic contexts on and around the body such as body positions/movements, multi-paths wireless interferences, RF transmission power, node's battery level, etc.

The followings are a few major technical challenges those must be resolved in order to design and develop reliable and continuous health monitoring applications using WBAN.

- Employs the lowest possible RF transmission power and keeps minimum resource usages while ensuring the application dependent optimal packet delivery ratio (PDR).
- Enables fair sharing of available wireless bandwidth but guarantees reliable priority schemes for delivering time critical events.
- Supports dynamic topology and wireless operation scheme (RF power level, network route, etc) according to the changing WBAN contexts such as user activity,, environment state, etc.

Due to application specific requirements, it is necessary to evaluate reliability and performance of WBAN operations in settings resemble to actual application space. In order to assist developers in implementing such WBAN system for particular applications, a set of experimentation are required to conduct developing appropriate scheduling, routing, eventing and fusion schemes. But, such network parameters can drastically be affected when there are on-body movements [3] and RF interferences. So WBAN protocols must change its operation parameters on the fly according to dynamic network contexts to achieve desirable application's Quality of Service (QoS) demands.

B. System Design and Architecture

Considering extensibility and modularity as top priority, we adopted three-tiered architecture as shown in Fig. 1 for our testbed. The separation of different tiers enables to support both platform and protocol independent requirements in dealing with different WBAN systems. With minimum overhead of application-level message size added to any underlying networking scheme, our testbed can work with different WBAN platforms and various networking protocols.

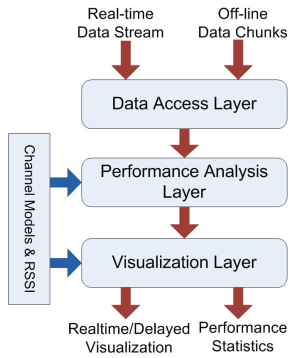

Figure 1. 3-tiered WBAN testbed architecture

The first tier, data access layer, acts as an interface between WBAN nodes and the rest of the testbed components to exchange information for both visualization and performance evaluation. It supports retrieving information from real-time data stream, delayed data as well as offline data chunks from persistence storages. It is also responsible for logging network states and recording performance statistics and testbed parameters. The second tier, performance analysis layer, performs performance evaluation of developed protocols with data accumulated at the sink node using appropriate channel model, network profile and application QoS parameters. Depending on the granularity and the type of evaluation performed, several system fined tunings and analysis criteria can be included according to the application goals. The third tier, visualization layer, mainly does effective representation of different WBAN parameters and protocol operations as well as rendering body positions according to movements performed by the subject through 3D motion reconstruction and modeling. It also supports both real-time live display and replay of system states and protocol operations continuously. Different software components and their functionalities implemented in each tier will be explained details in section III.

C. Testbed Design Goals and Features

With challenges mentioned previously, our application design goal is to develop a reusable and reconfigurable testbed for users and developers to evaluate their WBAN performance in realistic settings. The implementation design goal is to support different hardware platforms and to modify or extend its functionality according to user needs. In accordance with these design goals, the salient features of the testbed can be summarized as follows:

1) Platform and Protocol Independent Usage: By adding the parameters related to visualization and performance evaluation as application level overhead [8] in WBAN messages, our testbed can work independently with various underlying protocols. The data access layer can act as proxy for specific platform and it allows creating a new data access proxy according to the interface specifications. This enables to receive unified WBAN information from different platforms.

2) Flexible and Modular System Design: The modular software design allows the developers to easily extend or modify functionalities required in their applications. The well-defined interface specifications and minimal message overhead allows flexible integration with third party software and hardware components.

3) Dynamic WBAN Parameters Visualization: The process of visualization does not only represent static node status but also displays dynamic protocol operations and multimodal sensor data. Also, it displays online network traffic from WBAN sink in either real-time or delayed visualization mode, and offline traffic from pre-recorded data files or databases.

4) Network Performance Evaluation: Performance analysis function will process accumulated node and network statistics during its operation to measure overall performance metrics of WBAN [9]. Optionally, protocols can be designed to adapt in accordance with changing network contexts and wireless channel models by adjusting associated system parameters.

5) 3D Visualization of Body Movements and Postures: This testbed will incorporate contextual knowledge obtained from dynamic body positions and motions that corresponds to changing inter-node positions and wireless communication. 3D visualization with humanoid model will enable to animate body movements such as subject running on treadmill together with network statistics. By correlating body movements and node positions, adaptive routing and scheduling will be made according to the spatial-temporal association among connected WBAN nodes. With developed statistical path loss model and RSSI-distance correlation profile, desirable reliability and resource management can be achieved corresponding to static and dynamic body positions. Our visualization component will integrate motion information with multimodal sensor data to display network protocol statistics as well as to manage WBAN operation parameters as shown in Fig. 2.

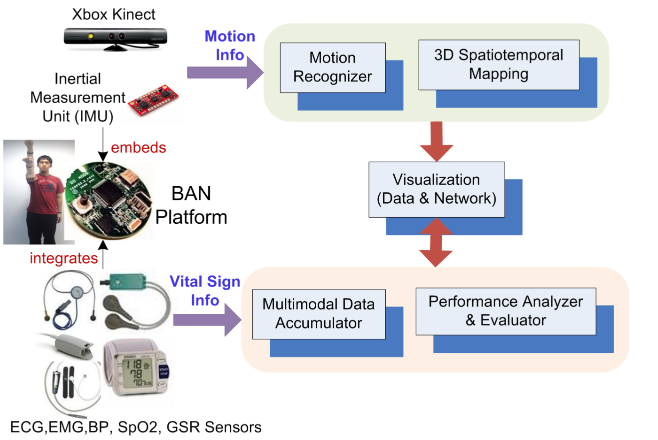

Figure 2. Visualization of different sensor data correlated to motion

With these design goals, vision-based motion recognition sensor, Xbox Kinect (http://www.xbox.com/en-US/kinect) is used for visualizing 3D body postures and movements. Also, inertial measurement unit is integrated into WBAN to recognize body motions and postures to adjust network characteristics. As body movements and position affect RF channel characteristics and reliable data delivery [3, 5], exact visualization of network profile with body movements can enable developers to analyze and adapt their protocols according to the body dynamics.

III. TESTBED EXPERIMENT DESIGN AND IMPLEMENTATION

A. *Software Components and Implementation*

Along with challenges identified, the following technical considerations were made into the design and development of proposed WBAN testbed. Especially in WBAN applications, it is important to apply minimum RF transmission power while maintaining high data reliability and efficient resource management. As part of performance evaluation and reliability enhancement of WBAN, we first studied the coherence time between a pair of different nodes placed over the body. From our experiment testing, that parameter plays important role in altering protocol operations dynamically in order to maintain desirable PDR. We then conducted different experiments to examine the correlation of RSSI and distance between a pair of nodes with or without attaching them to the body. These two RF profiles will be kept inside database to infer optimal system parameters those correspond to underlying network dynamics and application's QoS requirements. Our proposed testbed can be realized by implementing different software components in each system tier as shown in Fig. 3.

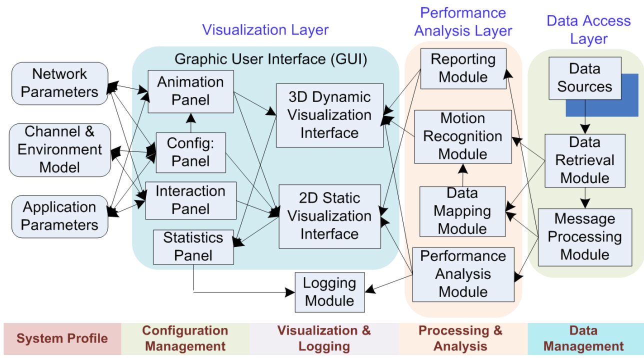

Figure 3. Software modules involved in testbed implementation

Instead of interpreting and representing data streams from heterogeneous sensing data semantically, our testbed is mainly designed to examine on network parameters such as PDR, network throughputs and guarantee of critical event delivery according to predefined application criteria. Besides network metrics and wireless statistics, individual node health and performance indicators will also visualize. WBAN embedded applications will be integrated node and network parameters such as RSSI, parent node, RF power level, message type, etc. in messages transmitted from different source nodes to sink node [9]. If any individual node state is required to alter during real-time system operation, users can define their own operation types and implement relevant functionalities to support desirable node controls. The required parameters for both upstream and downstream messages can be defined and setup from the configuration panel of testbed's user interface.

The data management modules are responsible to retrieve data from online and offline data sources as well as to extract relevant network parameters. Then, 2D visualization interface is developed to display basic network and node states such as RSSI, link quality, network route, RF power level, node's battery level, PDR, etc for static body position. Moreover, modules for logging and reporting are implemented to report a set of basic network metrics [9] and statistics for performance evaluation. Finally, software modules for motion recognition and spatial mapping of 3D animation with node coordinates are integrated by extracting motion and position states from external sensors. Additionally, configuration and interaction panels can be used to control and manage relevant network and performance evaluation parameters.

B. Experiment Design and Application Scenarios

Unlike variable and huge numbers of nodes deployed in traditional environment sensing applications [6], total and maximum number of nodes in WBAN application is generally fixed [13]. In this testbed, a total of 16 source nodes and 1 sink node will be attached at specific positions and locations on the body. In order to support realistic performance evaluation, the first task is how to incorporate measured RF channel models and RSSI profiles into dynamic protocol management scheme to enhance data reliability and resource utilization. The current application scenario of our testbed can be found in Fig. 4. Different WBAN source nodes attached to the different body parts interact with sink node that is attached to the waist. The real-time exchange of packets between WBAN and, different software components can be done through wireless gateway attached to the computer where visualization and performance evaluation system is running.

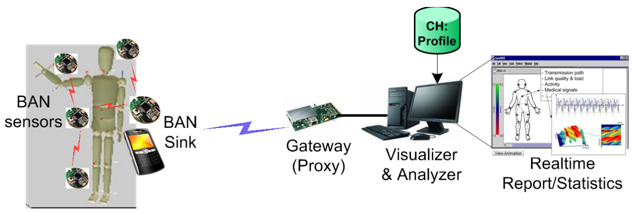

Figure 4. Experiment Design and Application Scenarios

IV. Discussion And Future Works

As of today, there is no specific tool or testbed to support visualization and performance evaluation of WBAN in real deployment settings. So we are trying to fill in this gap by implementing visualization and performance evaluation testbed for WBAN. Our testbed setup includes by attaching WBAN nodes to the body and considering various dynamic network characteristics. We are now building up required RF channel profiles and RSSI models, as well as developing framework and software modules for visualization and performance evaluation as we discussed previously. This will be beneficial to WBAN researchers and application developers to develop and test their solutions in a short time frame with our testbed .

From initial development stages, we identified testbed goals and features important for accelerating WBAN application development. Still, there are several technical aspects lacking from current works and a few possible extensions to cover these limitations. In current design, total numbers and locations of nodes on the body are fixed at initial stage. It is desirable to enable easy and dynamic configuration of variable numbers of nodes with associated coordinates on the body. This allows users to easily tailor WBAN settings according to their needs. Most importantly, experimentation and validation of existing testbed under different application scenarios is immediately required to prove its capability and usefulness.

V. Conclusion

We propose a testbed that supports efficient visualization and performance evaluation for WBAN. The goal is to evaluate devices and algorithms in realistic settings for developing healthcare applications. We firstly identified challenges and requirements healthcare applications using WBAN. Then, system design, testbed architecture and implementation details were discussed. Finally, we explained the current experiment design, application scenarios and possible future extensions of existing testbed. So we are hoping that this testbed will provide a valuable tool for WBAN developers to visualize various system states and operations. Moreover, our testbed will enable to inspect the performance of underlying networking protocols and processing schemes for specific healthcare setting.

References

[1] U. Varshney, "Pervasive Healthcare and Wireless Health Monitoring," *Mobile Networks and Applications*, vol. 12(2), pp. 113-127, 2007.

[2] H. Alemdar, C. Ersoy, "Wireless Sensor Networks for Healthcare: A Survey," Computer Networks, vol. 54(15), pp. 2688–2710, 2010.

[3] M. Patel and J. Wang, "Applications, challenges and prospective in emerging body area networking technologies," *IEEE Wireless Communications*, vol. 17(1), pp. 80-88, 2010.

[4] Sanna Ullah et al, "A Review of Wireless Body Area Networks for Medical Applications," Int. J. of Communications, Network and System Sciences, vol. 2(8), pp. 797-803, 2009.

[5] A. Peiravi and M. Farahi, "Reliability of Wireless Body Area Networks used for Ambulatory Monitoring and Health Care", Life Science Journal, vol. 6(4), pp. 5-14, 2009.

[6] R.A. Becker, S.G. Eick, and A. R. Wilks, "Visualizing Network Data," *IEEE Trans. Visualization and Computer Graphics*, vol. 1(1), pp. 16–21, 1995.

[7] L. Shu, C. Wu, Y. Zhang, J. Chen, L. Wang and M. Hauswirth, "NetTopo: Beyond Simulator and Visualizer for Wireless Sensor Networks," *ACM SIGBED Review*, vol. 5(3), pp. 2:1–2:8, 2008.

[8] R. Jurdak, Antonio G. Ruzzelli, A. Barbirato and S. Boivineau, "Octopus: Monitoring, Visualization and Control of Sensor Networks," *Wireless Communication and Mobile Computing,*, John Wiley & Sons Ltd, 1530-8677, 2009.

[9] M. Turon, "Mote-View: A Sensor Network Monitoring and Management Tool," in *Proc. of 2nd IEEE Workshop on Embedded Networked Sensors*, pp. 11–18, 2005.

[10] C. Buschmann, D. Pfisterer, S. Fischer, SP. Fekete and A. Kroller, "SpyGlass: A Wireless Sensor Network Visualizer," ACM SIGBED Review, vol. 2(1), pp. 1–6, 2005.

[11] L. Ma, L. Wang, L. Shu, J. Zhao, S. Li, Z. Yuan and N. Ding, "NetViewer: A Univeral Visualization Tool for Wireless Sensor Networks,". *IEEE Globecom 2010.* pp. 1–5, 2010.

[12] J.Y. Khan, M.R. Yuce, and F. Farami, "Performance Evalution of a Wireless Body Area Sensor Network for Remote Patient Monitoring", IEEE Int. Conf. on EMBS, pp.1266-1269, 2008.

[13] A. Natarajan, M. Motani, B. de Silva, K-K. Yap and K.C. Chua, "Investigating Network Architecture for Body Sensor Networks," in *Proc. of HealthNet 2007,* pp. 19–24, 2007.