A WLAN and Bluetooth Coexistence Mechanism for Health Monitoring System

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***Abstract*—The rise in world's aging population and escalating healthcare cost, necessitate directed research on new health monitoring paradigms. Upcoming health monitoring systems require the integration of heterogeneous wireless technologies, to achieve an 'anytime and anywhere' medical environment. The use of well established wireless technologies, such as Bluetooth and IEEE 802.11b Wireless LAN (WLAN) in medical environment, causes significant interference issue. However, existing coexistence mechanisms can not eradicate interference effectively and thus degrade the health monitoring system performances significantly. Therefore, an adaptive coexistence mechanism based on probabilistic packet scheduling with Quality-of-Service (QoS) provision is proposed in this paper.**

Keywords-coexistence; Bluetooth; WLAN; IEEE 802.11b

I. INTRODUCTION

Rapid convergence of information and wireless communication technology is revolutionizing conventional healthcare systems. Ubiquitous health monitoring is a new healthcare paradigm, aimed at providing medical healthcare to people 'anytime, anywhere'. Seamless integration of heterogeneous wireless networks in medical environment is thus vital in achieving this vision. Standardized wireless technologies, such as the Wireless Personal Area Networks (WPANs) which include IEEE 802.15.1/Bluetooth, IEEE 802.15.4/ZigBee and etc., and the WLANs which include IEEE 802.11b/g/e/n, are highly favorable. However, the operation of WPAN technologies such as Bluetooth with WLAN technologies in the 2.4GHz unlicensed Industrial, Scientific and Medical (ISM) band, brings into picture, challenges such as spectrum utilization, security, Quality-of-Service (QoS) provision, interoperability and the notable interference issue.

Interference in this paper refers to frame collisions between mutual or same wireless technologies. This poses a major problem for health monitoring system which requires strict QoS guarantee. It is clear that interference degrades the network throughput and hampers the deployment of multi-standard wireless communications in health monitoring system. Hence, a good coexistence mechanism that mitigates interference effectively is important.

The IEEE802 LAN/MAN standards committee has been leading the industry in tackling the issue of coexistence in two major efforts [5]. The formation of IEEE 802.19 Technical Advisory Group (TAG) in 2003 helps define the responsibilities of IEEE 802 standards working groups on coexistence. Second effort involves the IEEE 802.15.2 Task Group which published the IEEE 802.15.2 standard on coexistence between Bluetooth and IEEE 802.11b devices [4]. Solutions range from collocated-collaborative schemes implemented in the same device to non-collaborative schemes that rely on interference detection and estimation.

The collocated-collaborative schemes require the communication between heterogeneous protocol stacks implemented in the same device, and a common transmitter is used. This allows one wireless technology to delay or adapt its transmission when another wireless technology is accessing the wireless channel. The non-collaborative schemes rely on channel or network measurements, such as bit or frame error rate, signal strength or signal to interference ratio (often implemented as Received Signal Indicator Strength (RSSI)) to detect the presence of other devices in the band [6]. Two basic non-collaborative strategies involve Time-Division Multiplexing (TDM) and Frequency-Division Multiplexing (FDM). TDM introduces additional delay due to transmitter having to wait for error-free channel at the cost of reducing packet loss. While FDM techniques allocate different portions of frequency band to specific group of communicating devices or specific traffic streams. Neither the TDM nor the FDM technique can eradicate interference completely, and as in most reactive measures, communication is impacted before an adaptive mechanism can be triggered.

The objective of this paper is to propose a more effective and dynamic coexistence mechanism for the health monitoring system, where interference can not be tolerated. First, we analyze the interference issue for a health monitoring system which integrates the IEEE 802.15.1 standard based Bluetooth [2], and IEEE 802.11b based WLAN [3], in a retirement community or nursing home designed for elderly people in Section II. This is followed by a presentation of the proposed coexistence mechanism in Section IV. The performance of the adaptive coexistence mechanism is then compared against well-known coexistence mechanisms in literature in Section V. We conclude this paper with a summary in Section VI.

A. *Motivation and Contribution*

A health monitoring system on the human body is a multi-point to point network. Bluetooth which follows the master-slave protocol is a good candidate for health monitoring system

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with low latency requirement, and the Bluetooth power save mode provides low-power operation. This application targets off-the-shelf Bluetooth based medical monitoring devices available in the market and requires minimum software upgrades.

The health monitoring system suffers from three interference scenarios as shown in Figure 1. Interferences occur between (i) collocated WLAN and Bluetooth, (ii) WLAN from one device with Bluetooth from another device, and (iii) Bluetooth in one piconet with Bluetooth from another piconet. The collocated-collaborative mechanisms such as Alternating Wireless Medium Access (AWMA) and Packet Traffic Arbitration (PTA) in [4], require prior knowledge of WLAN transmission, and solve case (i) only. On the other hand, recent non-collaborative mechanisms such as in [7], attempts to resolve scenarios (ii) and (iii) using long and inefficient interference detection and estimation method.

To overcome the above issues, we propose a Bluetooth and WLAN coexistence mechanism implemented at the Bluetooth master side. We reduce the interference detection duration significantly by using the RSSI information from WLAN, and the channel activity is factored into our algorithm to estimate the level of WLAN interference in a more accurate manner. Channel activity is obtained from the Channel Utilization (CU) field in Beacon frame [8]. Additionally, a probabilistic scheduling scheme is incorporated into a TDM-based frame transmission scheme.

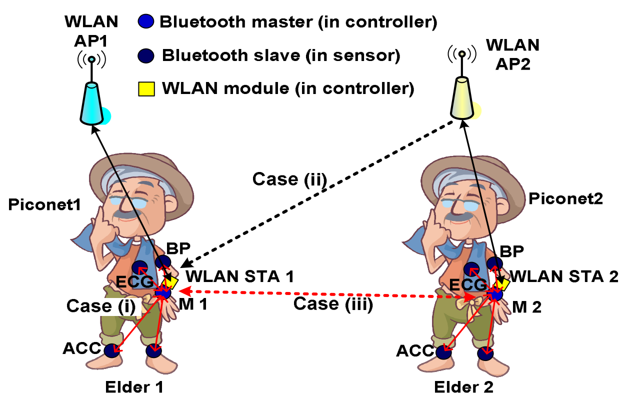

Figure 1. Three interference scenarios in a typical health monitoring system.

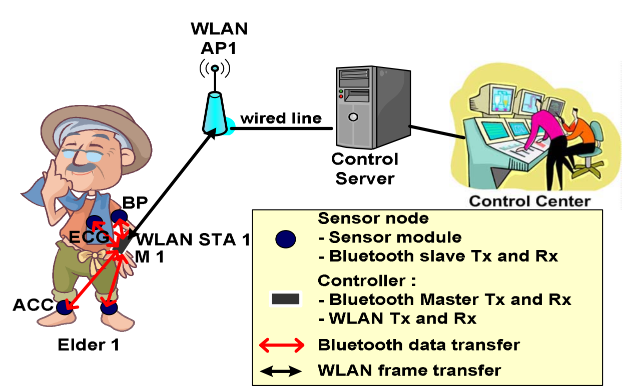

Figure 2. The network architecture and system configuration for health monitoring system.

II. Health Monitoring System

This section describes the health monitoring scenario for elderly in a retirement community or nursing home. The Electrocardiogram (ECG), Blood Pressure (BP), and 3-axis ACCeleration (ACC) signals located on the body of elderly people are monitored and recorded to the main control center (healthcare service provider).

The network architecture of this system consists of two layers. The first layer is defined by the Body Area Network (BAN), which constitutes of the communication between sensors on the body with the controller on the wrist as seen in Figure 2. This is implemented with Bluetooth technology. The second layer transmits the healthcare information received from Bluetooth to the infrastructure network through WLAN.

In a typical health monitoring mode, the ECG, BP and ACC sensors measure the medical signals, store the data in memory and send them to the controller periodically through Bluetooth technology. This is an uplink and uni-directional transfer. The Bluetooth device in the sensor node operates as a Slave (S) and the Bluetooth device in the controller acts as a Master (M). The controller receives data from all sensor nodes in round robin manner and stores all the data in buffer queue. The controller acts as a ‘gateway’ that links the BAN to WLAN infrastructure. The buffered WLAN data is then transmitted to the WLAN Access Point (AP) through IEEE 802.11b WLAN technology. This is also an uplink and uni-directional transfer. Figure 3 depicts the traffic pattern in typical health monitoring mode.

For emergency cases, data transmission operates as follows. When sensors detect a life-threatening sign, for example the ECG signal reaches a critical threshold, the controller shall recognize the danger, and transmits a warning message piggybacked onto the ECG data to the control center. An emergency team can be immediately dispatched to assist the elder person in distress.

Take note that other WLAN traffics due to email or internet activities exist in a health monitoring environment.

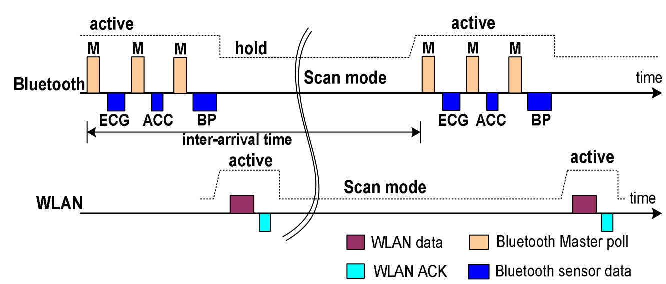

Figure 3. Bluetooth and WLAN frame exchange sequences.

III. Wireless Standard Review

A. Bluetooth

The IEEE 802.15.1 standard [2] for Bluetooth Medium Access Control (MAC) and Physical (PHY) layers is developed based on the Bluetooth Special Interest Group (SIG) Specification of Bluetooth version 1.1 [9].

Bluetooth devices implement the frequency hopping through 79 1Mhz-wide hop channels at 1600 hop/sec with 1Mbps raw data rate. Frequency hoping technique helps to mitigate interference to some extent. However due to the fact that Bluetooth channels are spread over the entire ISM band and have a narrow channel spacing, interference from IEEE 802.11b WLAN products, which operates in the ISM band with a higher transmit power, presents a problem.

Bluetooth supports two different link types for transmissions: Asynchronous Connectionless Link (ACL) for data, and Synchronous Connection-Oriented (SCO) link for voice. In this work, ACL operation is used.

Bluetooth performs packet exchange using time slot-based Time Division Duplex (TDD). A single slot is 625us. The Bluetooth master transmits packets in even slots and slave in odd slots. The slave sends a response packet after receiving a poll packet from master in the ACL link. Table I shows the Bluetooth system parameters.

TABLE I. SYSTEM PARAMETERS OF IEEE 802.15.1 BASED BLUETOOTH

Bandwidth		1M for each channel (Symbol rate = 1Mbps)
Max data rate		1Mbps
Modulation		GFSK
Duplex Transmission		TDD (Time Division Duplex)
Network ability		piconet (up to 7 slaves), scatter-net.
Error correction scheme		FEC(3/2, 3/1), ARQ by CRC and HEC check
Transmission Power	Class 1	Max: 20dBm, Nominal: N/A, Min: 0dBm
	Class 2	Max: 4dBm, Nominal: 0dBm, Min: -6dBm
	Class 3	Max: 1mW(0dBm), Nominal: N/A, Min: N/A
Range		~10m: class2 (0dBm Tx. Power)
Supported link type		Supported link type: Data (ACL link), Voice (SCO or eSCO link), mixed with data and voice

B. *IEEE 802.11b WLAN*

IEEE 802.11b standard [3] describes the MAC and PHY layer specification for WLAN in detail. Currently, IEEE 802.11b based WLAN is the most widely used standard in WLAN infrastructure network.

1) *PHY Layer*

The 802.11b PHY is based on the Direct Sequence Spread Spectrum (DSSS) technique. It supports four data rates from 1Mbps, 2Mbps, 5.5Mbps to 11 Mbps. Figure 4 shows the default long Physical Layer Convergence Procedure (PLCP) PHY Protocol Data Unit (PPDU) frame format followed by this paper.

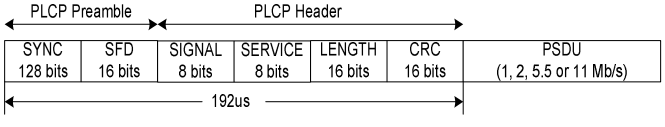

Figure 4. Long PLCP PPDU format.

2) *MAC Layer*

The IEEE 802.11b MAC layer is based on the legacy IEEE 802.11 standard [8]. There are two basic channel access protocols, known as Distributed Coordination Function (DCF) for contention based access and Point Coordination Function (PCF) for contention free access. The DCF-based Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme is found in all IEEE 802.11 based commercial products. In CSMA/CA, a station starts to transmit the first frame after a random backoff count and a Distributed (coordination function) Interframe Space (DIFS) duration. Each backoff count takes 20us and DIFS is 50us. There is a Short Interframe Space (SIFS) duration of 10us in between packet transmission.

IV. THE PROPOSED COEXISTENCE MECHANISM

A. *Analysis of Coexistence Mechanism in Literature*

Pairing existing collocated-collaborative mechanism with non-collaborative mechanism is suboptimal and does not solve all the interference issues mentioned in Section IA effectively. To illustrate this, we calculate the duration to estimate interference in a typical non-collaborative mechanism. A Bluetooth device requires about 100 Bluetooth packets to achieve certain level of confidence in detecting the status of a single channel. With reference to Figure 3, there are only three Bluetooth packets in one inter-arrival time. Inter-arrival time is set to 40ms, as obtained from simulations calculating the desired Packet Error Rate (PER) with varying WLAN inter-arrival time, PHY rate, retry limits and payload size. Thus, interference detection duration is 100*40/3 = 1.33sec per Bluetooth channel. This gives a total of 105sec for 79 channels. Interference detection alone takes up all the precious channel bandwidth especially when mobility is factored in.

Besides that, without considering the network load, a Bluetooth device may wrongly abandon 22 MHz of frequency bands, due to coincident collisions with occasional long WLAN packet, and the infrastructure network is actually not saturated.

Furthermore, non-collaborative schemes such as the well-known AFH are not suitable for collocated scenarios as the signal power from WLAN may overwhelm the AFH circuitry that is scanning for potential interferers.

B. *An Adaptive Coexistence Mechanism*

The proposed adaptive coexistence mechanism is separated into two parts: (i) scan mode and (ii) active mode, as described below.

During the scan mode, WLAN scans through 11 overlapping WLAN channels for Beacon frames. The measured RSSI value in Beacon frame provides the channel status information while the channel utilization value in Beacon frame provides the network condition information. This information is stored. The BSS Load Element in Beacon frame consists of channel utilization field and the channel index APs [8]. Scan period is 10ms. Active and passive scans can be used interchangeably.

During the active mode, if a Bluetooth master has a pending transmission, it shall check for the WLAN activity from co-located WLAN module. To do this, available collocated-collaborative schemes can be used. The PTA scheme is found suitable for this purpose. If there are on-going co-located WLAN activities, Bluetooth shall suspend the pending transmission. Next, the Bluetooth master determines whether the selected hopping channel is part of any used WLAN channel. If this hopping channel does not belong to any WLAN channels, Bluetooth master is free to transmit the poll packet. Otherwise, Bluetooth master will schedule the transmission based on a calculated WLAN channel occupancy probability value. This probability value is generated using probability models, such as a simple uniform random distribution or a more complex equation as in [7]. The flowchart in Figure 5 shows the algorithm of the proposed adaptive coexistence mechanism, implemented in the health monitoring controller.

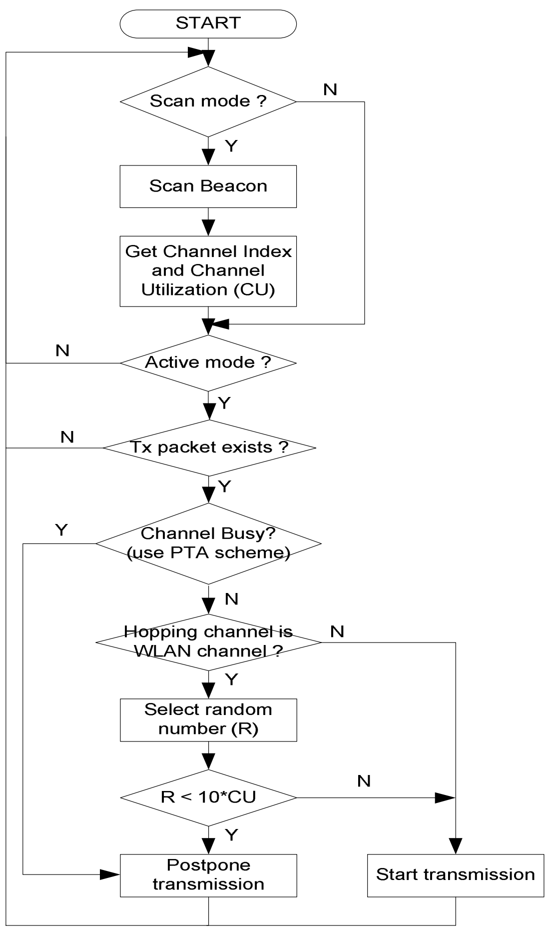

Figure 5. The proposed adaptive coexistence algorithm

V. Performance Evaluation

A. Simulation Environment

For clear simulation understanding, we categorized the elderly people in a health monitoring system into ‘reference user’ and ‘interference user’. In our simulation, there is one reference user surrounded by multiple interference users, as shown in Figure 7. Number of interference users are randomly generated from a uniform distribution and located within a radius of R = 5m around the reference user. The maximum number of interference users is 15. This scenario reflects occasions when elderly people gather together or exercise in halls.

One elder has 3 Bluetooth slaves embedded in medical sensors and one Bluetooth master inside the controller as shown in Figure 6. DM3 packet format is used and transmit power is configured as 0dBm.

To portray the WLAN interference, an AP is inserted at 25m from reference user. RTS/CTS protective mechanism is turned off, retry limit is set to six and transmit power is 14dBm. Simulation time is 5mins long.

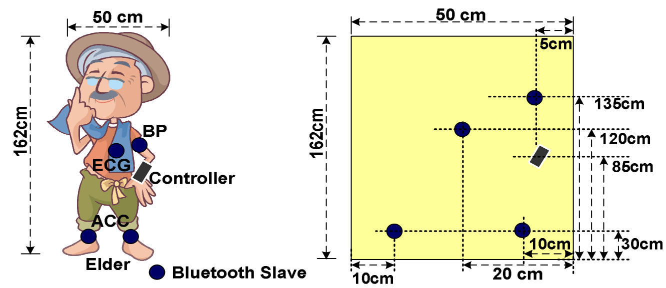

Figure 6. A single piconet structure for one elderly person

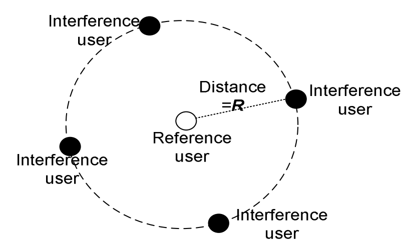

Figure 7. Location illustration between reference user and interference users.

TABLE II. Bluetooth and WLAN Payload Size

Inter-arrival Time (ms)	Medical signals payload size (byte)			Sum (byte)
	ECG	ACC	BP	
40	93	35	61	189

B. Simulation Results

We compare the performances of our proposed coexistence mechanism (proposed) with the (i) collocated-collaborative scheme (PTA), (ii) non-collaborative scheme (AFH), and (iii) no coexistence scheme (w/o scheme), in the health monitoring system described in Section II.

Figure 8 to Figure 11 compare the QoS performances in terms of throughput, end-to-end packet delay, packet drop rate and Bit Error Rate (BER), with increasing number of interference users. The required packet delay bound is 2sec and required BER is 0.001 [10].

Figure 8 shows that the proposed coexistence scheme maintains a required throughput of 37.8Kbps up to 15 interference users. The AFH and PTA schemes support six number of interference users only. Throughput is the lowest when no coexistence scheme is applied. Figure 9 shows the end-to-end packet delay performances for the health monitoring system when proposed, PTA, AFH and no coexistence schemes are used. The proposed adaptive coexistence scheme gives a 24.5% less packet delay compared to PTA and 46.9% packet delay improvement compared to AFH at 15 interference users.

Figure 10 shows the Bluetooth and IEEE 802.11b WLAN packet drop rate. The required packet drop rate is 0.01 and the proposed scheme satisfies this requirement. The number of packet loss for the proposed scheme increases at a slower speed compared to PTA and AFH. The packet drop rate for the proposed adaptive coexistence scheme is 2.5 times less than PTA and 5.25 times lower than AFH at 15 user interferences. Finally, Figure 11 shows the BER for Bluetooth transmission under the influence of WLAN and other Bluetooth piconets. Our proposed adaptive coexistence mechanism successfully maintains the required BER of 0.001 up to 12 interference users.

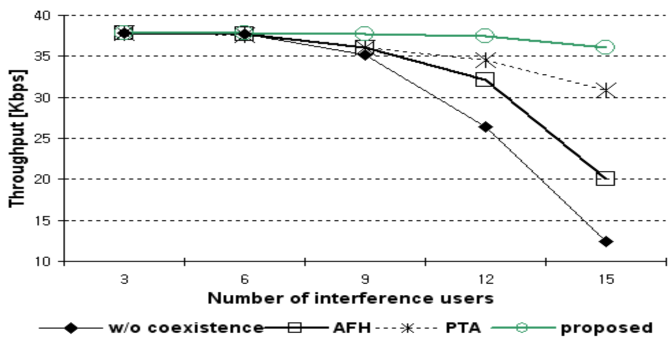

Figure 8. Throughput performance with increasing number of interference users.

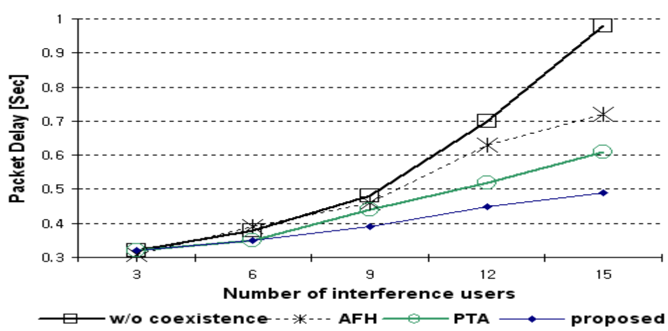

Figure 9. Average packet delay with increasing number of interference users

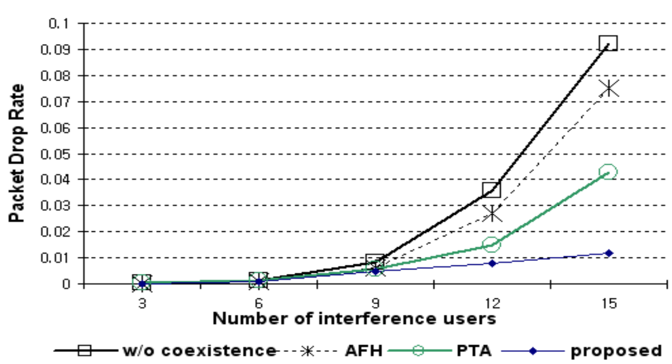

Figure 10. Packet drop rate with increasing number of interference users.

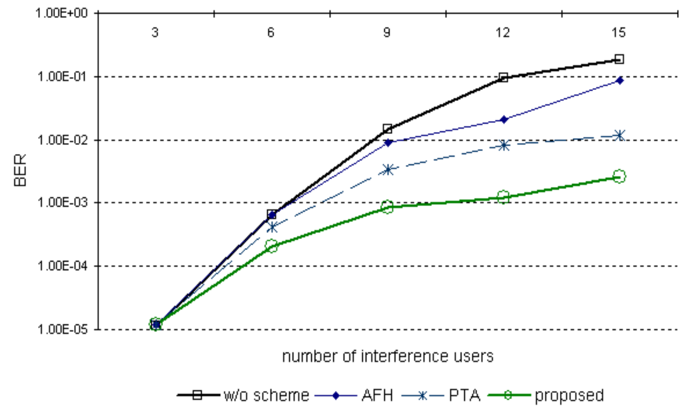

Figure 11. BER performance with increasing number of interference users

VI. CONCLUSION

In this paper, an adaptive coexistence mechanism with probabilistic scheduling method is proposed to mitigate interference for the health monitoring system. Compared to well-known coexistence schemes such as PTA and AFH, the proposed coexistence mechanism is capable of mitigating interference more effectively to achieve better QoS performances in terms of BER, throughput, end-to-end packet delay and packet drop rate. The simulation results clearly demonstrated that our proposed algorithm is successful in adapting the Bluetooth transmission schedules based on channel condition and network load, to provide QoS provision for ubiquitous health monitoring system.

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