Communication protocols for Body Area Networks

M. Maman, D. Miras and L. Ouvry
(CEA-Leti Minatec)
mickael.maman@cea.fr
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System Integration

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CEA Contributions

- CEA is responsible for the development of the communication protocol stack and the profiling (i.e. adaptation of its parameters to end-user scenarios) for applications.
- This protocol enables forwarding of the data coming asynchronously from the various BAN sensors so that individual data transmitted by each is easily identified, received without error and transmitted to a central station for further processing and visualization.
- This support both motional and emotional kind of sensor data, with their respective Quality of Service (QoS) requirements.
- The communication protocol runs onto the Wear-a-BAN SoC and is responsible for transmitting and receiving the user data between the different devices of the network.
- CEA have to validate the performance of a network composed of heterogeneous modules from a networking and radio perspective and to optimize the protocol for the Wear-a-BAN chip (WAB SoC)
Context

- **Shadowing depth and duration** have a strong impact on system performance.

- **MAC specification** requires specific BAN investigations and optimizations due to the closeness of the human body and its environment.
Goals

- To **collect** multiple **real-time** motional and emotional sensors information of nodes at **different places** of the human body and to **wirelessly** transmit it towards dedicated devices, machines or computers.

- To provide a **complete** protocol stack from Sensors to End Users clients:
  - Design and **Optimization** of the WAB radio driver for low power and low latency switch
  - Design custom MAC communications protocol for WBAN
  - Design of the **Logical Link Control layer** providing flow control, traffic management and QoS
  - Design of the application **Scheduler** providing for example the frame type, the Remote programming and the Sensor control
  - Design the **interface** between WAB node and the **PC**
Goals

- To implement a self organizing adaptive, flexible and low-power communication protocols for BAN
  - Unique: a common protocol architecture for several applications
  - Flexible (Network size, topology, communication...)
  - Adapted to BAN
  - Guaranteeing good QoS (reliability, latency,...)
    - Dynamic and Automatic relaying mechanisms mitigating the shadowing impact on PER
  - Optimized low power consumption for a long autonomy
  - Providing network functionalities (association, self-organizing, data collection...)
  - Transparent for the application thanks to several profiles
    - Autonomously and dynamically adaptive
    - Trade off between QoS and energy consumption
    - Adapted to several applications
    - Adapted to heterogeneous traffics
System Integration

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2.1. Network topology and devices roles

- **Network topology**
  - Star mesh hybrid topology

- The approach is to base the Wear-A-BAN MAC specifications on the IEEE 802.15.4/IEEE 802.15.6 standards with these main deviations:
  - Support for **peer to peer** communication, whereas 802.15.4 requires mediation from the coordinator to allow it.
  - **Systematic** usage of guaranteed time slots for data transmissions.
  - Specification of the **relaying procedure**.
  - Dedicated time slots for monitoring and allocation request.
  - **Simplification of association** and transactions to allow **very low complexity** implementations.
  - **Simplification of initialization** procedures.
  - Adapt to **Body Area Networks**
2.1. Network topology and devices roles

- **Device roles**
  - **Coordinator**
    - Sends *beacon* for synchronization and Superframe management
    - Accepts node *associations*
    - Manages *allocated slots* for the different flows.
  - **Central node**
    - Connected to the PC
    - Collects the data from different Sensors nodes.
  - **Sensors nodes**
    - *Synchronize* on the beacon
    - *Request* to the coordinator *an association* and a short address
    - *Request* to the coordinator *GTS slots*. 
2.2. Layers Description

Remote Programming Client

PC

USB JTAG

WAB

node
2.3. Abstraction Layer

Diagram showing the layers and components of the Abstraction Layer:

- **Emotion Sensor Client**
- **Motion Sensor Client**
- **Remote Programming Client**
- **…**

Wrapper (COM to UDP)

Driver (USB to COM)

FTDI (UART to USB)

Remote Programming

Application

…

Application framer

LLC

MAC

Abstraction Layer

WAB Sensors

WAB Radio

WAB Timer

PC

USB JTAG

KEY WAB

WAB node
2.3. Abstraction Layer

- The Hardware Abstraction Layer provides a programming interface (API) between the protocol stack and the drivers for the specific WAB platform.
- With this Radio state machine, we define a trade off between the energy efficiency and the radio latency.
- For each mode, we can define its power consumption and the necessary time to switch in RX/TX Mode.
- Depending on its latency constraint, the MAC layer can choose the most energy efficient radio state.
2.4. MAC protocol layer

Diagram showing the MAC protocol layer with various clients, frames, and layers including:
- Emotion Sensor Client
- Motion Sensor Client
- Remote Programming Client
- …

Layers include:
- Application framer
- UART framer
- Remote Programming
- Application
- …
- Application framer
- LLC
- MAC
- Abstraction Layer
- WAB Sensors
- WAB Radio
- WAB Timer

Connectors to:
- PC
- USB JTAG
- KEY WAB

Remote Programming Client
Motion Sensor Client
Emotion Sensor Client
Remote Programming Client...
2.4. MAC protocol layer

- The Medium Access Control (MAC) Layer provides channel access control mechanisms to several communicating devices.
- The MAC layer is responsible for:
  - The network formation
    - The association and disassociation of devices to the network,
  - The maintenance of the network
    - Manage the list of the node in the BAN
  - The management of the access to the radio channel.
    - A TDMA, centralized and beacon based protocol, inspired from the IEEE802.15.4 standard and, more recently, from the IEEE802.15.6 standard.
    - A dedicated format of the superframe delimited by beacons, with CAP, PAP, CFP and inactive periods
  - The management of the traffic:
    - Traffic allocation/deallocation and expiration
    - Acknowledgment and retransmission policies
    - Time to live
    - Data relaying
    - Manage the duplicate data
2.4. MAC protocol layer

- **Beacon Period**: Dedicated to the coordinator. Each node can synchronize and update its knowledge of the BAN.
- **Indicator Period**: Each device has an attributed Poll minislot for sending back ACK to beacon. During this period, each node can advertise the coordination and other BAN nodes for neighbour discovery, relaying functionalities...
- **GTS Period**: Guaranteed time slots dedicated to the report of data to the coordinator.
- **PAP+CAP**: During these Periods slotted ALOHA access i.e. with slot allocation. With the split of the CAP, emergency traffic is protected from control traffic.
- **Inactive part**: Each node can switch off their radio and save energy.
2.4. MAC protocol layer

- **MAC functionalities**
  - **Starting a BAN**: The coordinator begins operating the BAN and using a new superframe configuration
  - **Beacon generation**: Generate and transmit beacon frames
  - **Beacon Synchronization**: Devices can get synchronized by receiving and decoding the beacon
  - **Association Procedure**:
    - Once synchronized, a device requests to the coordination an association and its short address.
  - **Disassociation Procedure**:
    - A device can request to the coordination a disassociation when it missed MAC_MAX_MISSED_BEACON beacons
    - A coordination can force a disassociation when it missed MAC_ALIVE_NODE_CNT poll node packet
  - **Poll Period**: During this period, each device sends back a poll node packet to the coordinator indicating its presence.
2.4. MAC protocol layer

- Relaying Procedure
  - During the Poll period, each device has an attributed poll slot for sending back an poll notification to all nodes in the BAN.
  - Each device listens to the poll slots and uses the channel reciprocity. The poll packet reception will define the instantaneous reliability of a link.
  - In order to select the route (direct or relayed), the originator compares the reliability of the link with a threshold.
    - If the Received Signal Strength Indicator (RSSI) of Recipient-Originator link is under the threshold, the direct route is selected.
    - If the RSSI of Recipient-Originator link is not under the threshold, the originator selects the route with the best reliability i.e. the direct route of the relayed route with the best relay.

=> A dynamic relaying table is automatically built depending on the quasi instantaneous shadowing effect.
2.5. Logical Link Control Layer

- Emotion Sensor Client
- Motion Sensor Client
- Remote Programming Client
- …

- wrapper (COM to UDP)
- Driver (USB to COM)
- FTDI (UART to USB)

- Remote Programming
- Application
- …

- Application framer
- LLC
- MAC

- Abstraction Layer
- WAB Sensors
- WAB Radio
- WAB Timer

PC
USB JTAG KEY WAB
WAB node
2.5. Logical Link Control Layer

- The Logical Link Control (LLC) sublayer provides an interface between upper sublayers (e.g. Application layer) and the MAC data communication protocol sublayer.
- The LLC provides:
  - flow control of data to MAC sublayer
  - Buffer management mechanisms
  - Traffic (Bandwidth)
    - Permanent Traffic: permanent traffic set up when the connection is established.
    - Switched Traffic: Set up and released on demand via a procedures.
  - Quality of service
- A connection (an LLC flow) must be established before any packets are sent. Each flow category is defined by associated traffic, priority and QoS parameters.
- Several flows can be managed simultaneously by the LLC depending on the traffic generated.
  ⇒ This scheme permits to a higher flow priority to used bandwidth to a lower flow priority (e.g. emergency data used bandwidth to monitoring data)
2.5. Logical Link Control Layer

- A specific flow has to define a flow for each WAB scenario with one or two profiles.
- When the profile1 does not respect the requirement (e.g. loss rate), the flow can switch to Profile2 (Better Reliability but higher power consumption)

Flow
  - Type of flows
    - Network control
    - Remote programming
    - Emergency
    - Voice
    - Monitoring
    - Logging
    - Best effort
    - Excellent effort
  - Recipient address
  - Packet rate in ms
  - % of loss Rate Acceptable
  - Time To Live: time before discarding the data
  - Packet Rate statistics: useful to change profile
  - Profile 1
  - Profile 2
### 2.5. Logical Link Control Layer

<table>
<thead>
<tr>
<th>Flow category</th>
<th>Profile</th>
<th>Priority</th>
<th>Period</th>
<th>Ack</th>
<th>Permanent traffic</th>
<th>Switched traffic</th>
<th>Retransmit period</th>
<th>Relaying</th>
<th>Packet TTL</th>
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<th>Packet rate</th>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tbody>
</table>

- **In Monitoring category, two profiles have been defined for data reporting:**
  - **In the first profile,** the device transmits its data in allocated slots of the **CFP** and waits for an immediate acknowledgment.
  - **If the data is not correctly received,** it can send again this data in the **CAP** period of the same superframe.
  - **If the quality of service configurable by the application is not respected,** the monitoring flow can switch to the **second profile with relaying functionalities.**
2.6. Higher Layers

- Emotion Sensor Client
- Motion Sensor Client
- Remote Programming Client
- …

- USB JTAG
- KEY WAB

PC

- Driver (USB to COM)
- FTDI (UART to USB)
- wrapper (COM to UDP)

WAB node

- UART framer
- Remote Programming
- Application
- …

- Application framer
- LLC
- MAC
- Abstraction Layer
- WAB Sensors
- WAB Radio
- WAB Timer
2.6. Higher Layers

- The application framer layer directs the received packet from the LLC layer towards the specified application module.
- Definition of Several application modules for each scenarios
- The central node is able to program WAB nodes using the RF. Remote programming is an application using lower layers to transmit its frame.
- UARTs driver has been optimized with multi-UART functionality in order to:
  - support higher data rate between the central node and the PC. The complete chain throughput is up to 20Ko/s (Radio, MAC, UART, UDP).
  - direct the received packet from the UART module towards the specified module. The UART framer adds a terminator at the end of the frame in order to delimit the frame and converts binary hexadecimal to ASCII format.
2.7. Interface between WAB node and the PC

- The path between the application Layer of the central node and the PC is the following:
  - The FTDI interfaces the UART to the USB port (in USB JTAG).
  - In the PC, we interface the USB port with the COM Port using the driver.
  - In the PC, we can launch the Wrapper program which converts the COM Port Protocol to UDP Port Protocol and sends it to the corresponding client.

- The GUI client can interface using UDP protocol and WAB frame format.
2.6. Interface between WAB node and the PC

<table>
<thead>
<tr>
<th>Frame Type</th>
<th>Timestamp</th>
<th>ACC_X</th>
<th>ACC_Y</th>
<th>ACC_Z</th>
<th>G_X</th>
<th>G_Y</th>
<th>G_Z</th>
<th>M_X</th>
<th>M_Y</th>
<th>M_Z</th>
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<td>16 bits</td>
<td>16 bits</td>
<td>8 bits</td>
</tr>
</tbody>
</table>

- **The frame_type values are:**
  - Log 0x0x
  - Remote Programming 0x1x
  - Network management 0x2x
  - Motion Data 0x4x
  - Emotional Data 0x5x
  - RSSI 0x8x
  - Accelerometer 0x41
  - Gyrometer 0x42
  - Accelerometer and Gyrometer 0x43
  - Magnetometer 0x44
  - Accelerometer and Magnetometer 0x45
  - Gyrometer and Magnetometer 0x46
  - Accelerometer, Gyrometer and Magnetometer 0x47
  - Energy Expenditure 0x48
  - ...
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3. WAB Scenarios and Applications

- Application A: Robotics based rehabilitation
  - The objective of this scenario is to detect the amplitude of movements in an arm. This is achieved by placing a series of movement sensors in a textile base in the form of a wearable sleeve.

- 4 Motion Nodes
  - Measure the angular motion (gyroscope), the linear acceleration (accelerometer), and the orientation (magnetometer).
  - Transmit the motion sensor data to the Central Node

- 1 Central node and BAN coordinator
  - Manage the BAN.
  - Receive all sensors information and deliver it to the PC central unit.

- Define Adapted Profile
  - Type of flows = Monitoring
  - Packet rate = 20ms i.e. 50Hz
  - % of loss Rate Acceptable= 10%
  - Time To Live= 40ms
3. WAB Scenarios and Applications

- Application B: Daily life physical activity monitoring in Real Time
  - In this scenario, the nodes, and their communication protocol, have to support biofeedback functionalities which impact their real-time capabilities and technical specifications.
  - The expired monitoring data is retransmitted later using logging mode. No motion sensor data is lost.

- 3 Motion Nodes
  - Measure the angular motion (gyroscope), the linear acceleration (accelerometer), and the orientation (magnetometer).
  - Transmit the motion sensor data to the Central Node in Real Time.
  - Motion sensor data, which not respected specifications, are retransmitted in logging mode.

- 1 Central node and BAN coordinator
  - Manage the BAN.
  - Receive all sensors information and deliver it to the PC central unit.
3. WAB Scenarios and Applications

- **Application B**: Daily life physical activity monitoring in Real Time
  - In this scenario, the nodes, and their communication protocol, have to support biofeedback functionalities which impact their real-time capabilities and technical specifications.
  - The *expired* monitoring data is retransmitted later using logging mode. No motion sensor data is *lost*.

- **Flow for monitoring** for real time mode
  - Packet rate = 66ms i.e. 15Hz
  - % of loss Rate Acceptable= 10%
  - Time To Live= 100ms

- **Flow for logging** for expired monitoring data
  - % of loss Rate Acceptable= 0%
  - Time To Live= Unexpired
3. WAB Scenarios and Applications

- Application C: Daily life physical activity monitoring
  - In this scenario, each node has to collectively provide activity recognition and energy expenditure information without a constant connection to the central node and PC. In case of autonomous work, all information regarding physical activity is to be stored in a local memory of the BAN coordinator and sent to the PC once the connection is re-established with the Central node.

- 2 Motion Nodes
  - Measure the linear acceleration (accelerometer).
  - Compute activity index every second.
  - Transmit the energy expenditure to the coordinator.

- 1 Motion Nodes acting as BAN coordinator
  - Manage the BAN.
  - Receive all sensors information and stored in a local memory.
  - When the Central node is associated to the BAN, transmit data stored to the Central node.

- 1 Central Node
  - Receive all sensors information and deliver it to the PC central unit.
3. WAB Scenarios and Applications

Application D: Gaming

- This scenario presents a game that merge singing and dancing performance. The singing performance is scored by the use of an Emotion node (microphone sensor), while the dancing performance is done by the use of motion nodes (several movement sensors).

- 5 Motion Nodes
  - Measure the angular motion (gyroscope), the linear acceleration (accelerometer), and the orientation (magnetometer).
  - Transmit the motion sensor data to the Central Node.

- 1 Emotion Node
  - The microphone collects the audio.
  - Transmit the audio stream to the Central Node.

- 1 Central node and BAN coordinator
  - Manage the BAN.
  - Receive all sensors information and deliver it to the PC central unit.
3. WAB Scenarios and Applications

- **Application D: Gaming**
  - This scenario presents a game that merge singing and dancing performance. The singing performance is score by the use of an **Emotion node** (microphone sensor), while the dancing performance is done by the use of **motion nodes** (several movement sensor).
  - **Flow Monitoring** for motional node
    - Packet rate = 100ms i.e. 10Hz
    - % of loss Rate Acceptable= 10%
    - Time To Live= 100ms
  - **Flow Voice** for emotional node
    - Packet rate = 5 kHz => 10kBytes/s
    - % of loss Rate Acceptable= 10%
    - Time To Live= 16ms
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4. Network Demonstrator

- **Network Composition:**
  - 1 Central Node (coordinator) connected to the PC.
  - 5 WAB Nodes (device) embedded in the body.
  - 1 Headset Node with microphone.
  - 3 clients:
    - 2 Graphical User Interface in the PC.
    - 1 Java client for audio.
4. Network Demonstrator

- Traffic flows:
  - Network Control: To define the position of the node.
  - Best Effort: To measure the quality of the link between device.
  - Excellent Effort: To manage the motion capture.
  - Voice: To manage audio stream.
4. Network Demonstrator

- Traffic flows:
  - Network Control: To define the position of the node.
    - The device sends to the Central node the position in the network topology when it is associated to the BAN.
4. Network Demonstrator

Traffic flows:

- Best Effort: To measure the quality of the link between device.
  - The Device send neighbours RSSI information with multicast packet. All devices measure the link quality from this packet to reach the originator.
  - The Central node collect the neighbours RSSI tables from all the device associated to the BAN.
4. Network Demonstrator

- Traffic flows:
  - Excellent Effort: To manage the motion capture.
  - The device provide periodic motion sensor feedback to the Central Node.
4. Network Demonstrator

- Traffic flows:
  - Voice: To manage audio stream.
    - The headset device provides audio stream to the Central Node
4. Network Demonstrator

- **Network Topology**: Collect network management and topology information.

- **Motion sensor capture**: Collect motion sensor data of the targeted node.
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- A BAN is a **self-organizing network** at the human body scale which consists in a collection of smart, low-power, hardware-constrained, miniaturized and heterogeneous wireless devices attached to (or implanted into) a moving body.

- With respect to state-of-the-art, the Wear-a-BAN protocol is a very interesting piece of technology with respect to existing/emerging WBAN protocols since it provides all features to potentially map most the identified applications in the BAN area while offering the right level of performance. It also provides innovative features like physical layer profiling, dynamic relaying and traffic flows arbitration to optimize QoS and/or battery lifetime depending on user needs.
5. Conclusions

- Antennas design according to the application
  - Trade-off between efficiency and size in the presence of human body
  - Time-variant on-body channel, Space-time correlation properties