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Convergecast strategies for Wireless Body Area Networks environment: state of the art

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Abstract

It is now possible to use low-power, smart, micro-node sensors to monitor the functions of the human body. A wireless body area network (WBAN) is a wireless network consisting of a group of tiny biomedical nodes distributed on, under the skin, inside or near the body of some person. One of the most critical problems of this technology is that sensor nodes usually have limited energy because of its size. Data collection from nodes to sink is the major task performed by sensor nodes. Therefore, efficient data collection protocols allows for better energy consumption at the nodes. This article focuses on data collection protocols. These protocols referred to as convergecast strategies. This article studies the adoption of similar strategies in similar environment to evaluate their efficacy for being used in WBAN. Similar environment involves Delay Tolerant Network (DTN), Ad-Hoc network, Wireless Sensor Network (WSN), etc. Some of these strategies have been implemented and evaluated in terms of power consumption, end to end delay and end to end success rate. The results show that each of the existing strategies outperform the others according to a specific metric. It is ensured that, the performance of existing strategies deteriorate with the movement of the body which is a default behavior in WBAN. In addition, most strategies have high power consumption. Therefore, it becomes clear that existing strategies still need more improvements to cope with the specific needs of WBAN. In a future work, a data collection strategy from cross layer can be incorporated aiming to improve the power saving cab ability at the sensor nodes.

Keywords: Keywords— WBAN; Convergecast; Body Area Networks; Resilience;

1. introduction

WBAN is a subset of the (WSN) and (DTN). It has become the leading technology for health monitoring. It consists of a multitude of small, light, invasive, noninvasive sensors which are attached inside or outside the human body, it records body temperature, heartbeat, blood pressure, electrocardiogram, electroencephalogram and other physiological symbols of the body, it sends the data to the sink node to transfer [1]. These data help monitoring the patient's status 24 hours a day. In addition, node can identify changes and take preventive measures to prevent patients from getting into critical situations.

With these types of networks, sensor performance can be greatly affected by physical activity and wear on the body holding the sensor. There are several differences between WBAN and WSN: WBAN network size is usually less than 20 sensors. The arrangement of the network changes with the movement of the body. Wireless channels have special properties, such as the multiplicative effect of attenuating transmissions. Signals and additional effects can distort the signal received by the receiver. Communication links in WBANs are usually short and their quality varies depending on the body posture.

Because of these limitations, data collection is a critical issue in a WBAN environment. In addition to continuous body movement, the limitations of the sensor node capabilities make many existing protocols unable to meet the requirements in WBAN. This paper examines a number of existing data collection protocols to measure their effectiveness on WBAN. Our contribution consists in integrating the channel model proposed in [2] based on the real human pose (see Figure 1) into the OMNeT ++ simulator rich in the INET framework. Then compare the fusion broadcasting strategies in [3], [4] and emphasize them under realistic conditions. Then some evaluation matrices are measure including the end-to-end success rate, the end-to-end delay, and the number of transmissions and receptions.

The paper is structured as follows: part II examines relevant related work. In part III we describe the realistic channel model as it was integrated into the OMNeT++ simulator, and the mobile model used in this paper. In part IV, we present the classification of convergence strategies adopted by DTN, WSN and CTP networks and finally V part is evaluation results in terms of end-to-end delay, energy consumption and mobility resistance of the strategy, discuss the results and compare between the convergence strategies in part IV. Part VI contains conclusions and future work.

2. Related work

Convergecast protocols allow nodes to send data to the recipient. There are many convergent cast strategies in multiple domains such as ad hoc, WSN, DTN, CTP, and WBAN.

According to [5], the algorithm in DTN is generally divided into propagation (algorithm based on gossip) and forwarding (algorithm based on superposition). Gossip involves distributing any message to any node or any subset of nodes in the neighborhood. It is used when you don't have information about the network topology and nodes. Excessive form of gossip messaging is overlays to every node near the sender so, multiple copies of the message are copied to maximize the chance that the message will successfully delivered to its destination. At the same time, it offers near-optimal performance in terms of latency [5]. Large power consumption and overhead are the big problems of this protocol.

Tree-based overlays commonly used by overlay-based algorithms (dynamically created or pre-engineered) to send data from the source to the recipient via a preset path. Excessive form of gossip messaging is overlays. Each message is sent for each neighbor, to maximize the chance of delivering a successful message to its receiving node. Therefore, WBAN can be closer to certain types of DTNs designed to handle connection and interruption times. It takes over and handles discontinuous connection behavior, making the node operate in a (store and forward) mode, i.e., storing buffered packets until the desired connection occurs. Even with probabilistic transmission, a node can receive the same message in several situations.

The authors in [6] propose a method of transmission. They believe that there is no fully connected path between the sender and the receiver. To do this, the sender broadcasts information to its neighbors through the original leak. When two remote nodes finally meet, they only need to exchange lost data to reach their final destination. The Switching Center assumes that the memory has a list of all received messages for both nodes. Since the sensory node is characterized by a limited storage capacity, this method has several limitations in connection with WBAN, these limitations are associated with human mobility.

In [7] the author pays attention to the DTN routing issues, they consider the following special restrictions: the limited memory size of each node and knowledge of the path between the source and destination in the network. They proposed three algorithms: full knowledge algorithm, zero knowledge algorithm, and partial knowledge algorithm. Two scenarios used to compare these algorithms: remote village routing and urban bus network. The conditional parameters used to test these algorithms are not convenient to the WBAN situation.

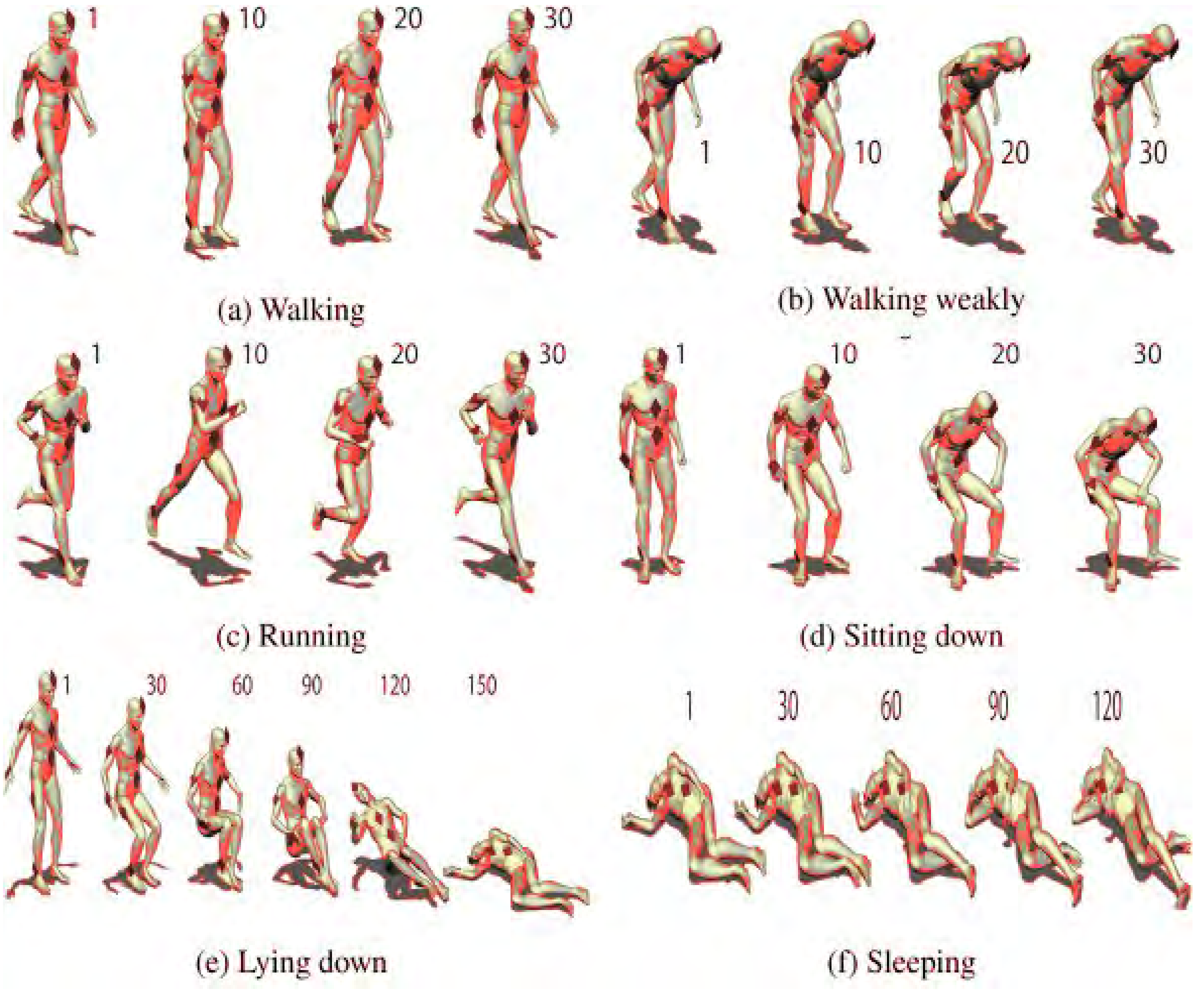

Fig. 1. Common poses for modelling WBAN channels ([2]). ((A) walking, (b) poor walking, (c) running, (d) sitting, (e) lying,

(f) sleeping.)

In [8] the author concentrated on the data-centered protocol SPIN (Information Sensor Protocol Through Negotiation) Routing Protocol. Multiple versions of the SPIN routing protocol have been discussed. The process of transferring data based on attenuation from sender to receiver is similar to the process used by these protocols. It is a three-way handshake to send data to the receiver and the node downstream. Modified SPIN version: M-SPIN [9] is very interesting for our work. Using M-SPIN, the sender sends the data to the receiver behind it. It uses the hop distance to calculate the distance. For example, the possible next hop metric is the attenuation of the connection between the sender and receiver. Distance is not an import metric for WBAN for two main reasons: first, nodes have a limited number of hop count, and second, body mobility. In connection with research into the SPIN protocol and its various versions, a comparison between floods and the SPIN protocol is proposed in the literature [10].

The DTN solution [11] and many other WBAN solutions use efficient dynamic source routing (EDSR) [12]. The author did not take into account that during the transmission of messages in the calculated path, there may be disconnections in human mobility, which leads to an error [13]. The author proposed in [14] effective n to 1

(Multipath Routing Protocol) for finding path from each sensor node to receiver in two stage path discovery using multipath update route discovery protocol and multiple path extension steps. In the flooding phase of the update route, the spanning tree is created by sending an update route message. When the receiver receives this message, it sets the sending node as the master node. Then, in the multipath expansion stage, the route will pass through nodes belonging to the various branches of the spanning tree. In contrast, in step n of data transmission, the source system splits its own data into several data packets and transmits them along different paths. If important data packets are lost, all data may be lost. The associated n-to-1 multipath routing protocol uses a flooding strategy during the route discovery phase. Therefore, especially in the WBAN network, it will cause high node power consumption and high network overhead.

In order to solve the problem of power consumption and data overhead, the author proposed a multi-path routing algorithm in [15], using the source node and the sink node of two conflict-free paths. Although their mechanism helps save more power consumption compared to [14]. There are two reasons to prevent it from being used in WBAN: body mobility and lack of ability to build two collision-free paths. In [16] the author proposed the CTP collection tree protocol. The basic idea is to build one or more trees, all trees have the recipient as their root. Each data node sends and forwards other data to the node. Based on the routing data (beacons) and the successful reception rate of the message, the metric is used to indicate the quality of the connection between the sender and its receiver node. However, these WBAN protocols have yet to be tested in real mobile face-to-face mode. In [3] the author adopted multipath strategies for WBAN networks, and these strategies performed well in terms of power consumption. However, when compared to gossip-based algorithms, they do not do well in terms of the reliability of human movement.

In the context of WBAN, a variant of the negotiation protocol is called a damping-based algorithm. Through simulation, we show that their performance degrades when these strategies are emphasized in the real-world WBAN environment. WBAN has proposed many routing protocols that can be divided into different categories according to their goals [17], [18] cross-layer, temperature-based routing protocols, QoS-based routing protocols and low-cost routing protocols. Most of these suggestions are inappropriate when the sensor is placed on the body. There are many challenges in placing sensors in the human body such as the battery life, the sensor maintenance and the sensor signals.

A key contribution of our work is to compare fusion broadcasting strategies to study its effects on WBAN and to obtain the best strategies in different body positions, it also studies the limitations of current strategies in the application of WBAN, to demonstrate the special needs of WBAN.

3. Channel model

The realistic channel model in [2] is used in the implementation of the physical layer given by the INET framework [19]. The channel model is obtained by a finite time difference method in the time domain to dynamically simulate a 2.45 GHz channel between 7 nodes on the body. These nodes are in the same WBAN, in the belly button, head, chest, upper arms and ankles, thighs and wrists, it is modeled with small directional antennas 1.5 cm from the body.

The node position is calculated in 6 postures: walking, walking weak (weak), sitting, running, sleeping and lying down. These postures are shown in Figure 1. Walking, weakness, and running are examples of walking movements. Sitting and lying down are changes in moving up and down. Sleep is a relatively irregular posture and movement.

To calculate the channel attenuation between each pair of nodes, the mean value and the standard deviation are showing in Table 1 [2]. It is a matrix in which the upper triangle represents the average attenuation and the lower triangle represents the standard deviation of attenuation between nodes (see Table 1). The model takes into account: shadows, reflections, diffraction and scattering of body parts. The same values are used in previous study [2].

Table 1: Measurement of the mean and standard deviation of the distance loss for a walking movement.

Tx or Rx	navel	chest	head	upper arm	ankle	thigh	wrist
Navel	–	30.6	45.1	44.4	57.4	45.8	41
Chest	0.5	–	38.5	40.6	58.2	51.6	45.1
Head	0.8	0.5	–	45.4	64	61.3	49.7
Upper arm	5.8	5.2	5.1	–	54.2	45.5	34
Ankle	4.3	3.4	5	3.1	–	40.6	48.9
Thigh	2	2.5	6.8	4.8	1	–	35
Wrist	5	3.6	3.8	2.5	3.8	3.3	–

Mean [dB]

Standard deviation [dB]

4. Convergecast strategies

This section introduces the various ways that convergent broadcasting works. In addition to dampening-based, gossip-based, multi-path strategies, hybrid and CTP and Opportunistic Routing Wireless Sensor Networks (ORW) can also be used to achieve the same goal. In order for every strategy to work in the WBAN environment, it must be adapted. This is based on the channel model described above.

4.1 Attenuation-based strategies [3]

These strategies are based on negotiating a channel attenuation. When the source has a data packet to send, it first sends an attenuation estimate request from the requesting destination to the source. The sensor node of the recipient of the request then sends back a response with the requested attenuation value. It describes the typical patterns of these strategies in Figure 2. Source S first broadcasts an 'AttREQ' request, asks for the link attenuation value between neighbor and sink and timer T setting. After T timer expires, S checks the received response: If there is no answer, S sends another request of attenuation "AttREQ" and reactivates the T-timer. Otherwise, S processes the replies if it receives at least one reply.

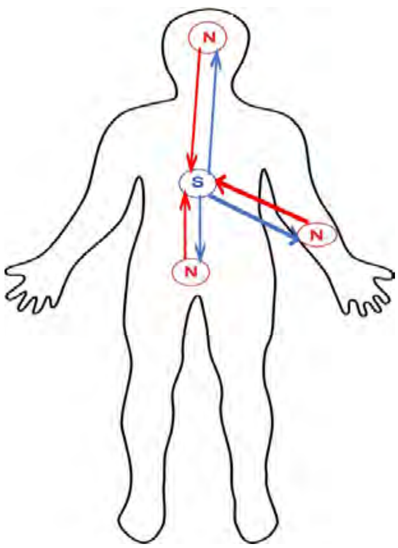

Fig. 1 Attenuation assessment procedure: (S) Source, (N) Node

It uses one of these strategies to process the response (MinAtt-BothMinAtt-CloseToMe).

- MinAtt: If you have a source with the smallest attenuation value, it will select that node as the next hop.
- BothMinAtt: These are the two lowest (best) values of attenuation among all responders.
- CloseToMe: two nodes are selected: In addition to asking for link attenuation between each node and the sink, Sink also requests the link attenuation value between it and each node receiving the request.

4.2 Gossip-based strategy [3]

This strategy means that the node sends each data packet to all other nodes on the network without depending on any information. It is adapted from WSN and DTN. Figure 3 describe the gossip approach. There are three main strategies:

- Flood-to-Sink: The node transmits its data and the received data to its neighbor's until they reach TTL.
- ProbaCvg: The node transmits its data and the received data packet with a certain probability (P) to its neighbors until the data packet reaches the receiver or TTL. Because the probability that each broadcast packet is forwarded is halved (for all nodes, P is initially set to 1, and a node divides P by 2).
- PrunedCvg: If nodes other than Sink receive a message, they will randomly choose which node is the next hop to which the message will be forwarded.

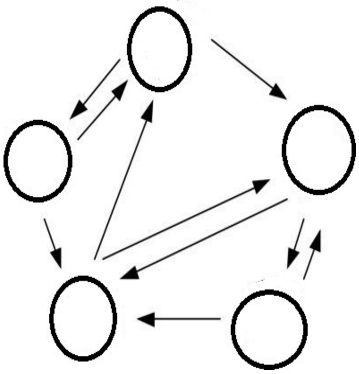

Fig.3 Gossip based approach where peers operate in parallel, and each peer communicate with one or more randomly selected partner.

4.3 multi-path strategies [3]

In these strategies, predetermined paths are used for routing. It consists of three different strategies.

- All parent nodes to all parent nodes: The node transmits the data packet to all its master nodes (APAP). As long as the packet does not reach the receiver
- All parent nodes to probabilistic parent nodes: Each source node sends its own data packet to all its parent nodes, and the parent node randomly forwards the data packet to one of its parent nodes (APPP).
- Probabilistic parent to probabilistic parent (PPPP): A node transmits data packets to its parent node in a probabilistic manner.

4.5 Hybrid strategy [3]

Multipath strategy and gossip strategy are combined into one. When a message is routed along a predetermined path, its behavior is similar to a multipath strategy. In fact, the node checks the link status of its parent node before sending any data message. The following is the working principle of the mixed working method. If a node needs to send a message at time (t), it delays message delivery by t + T and sends a PING message to its parent node. To respond to a PING message, the parent node must be within range of the node.

When it receives a response, it sends a message to its parents. If the node does not receive a response after the timer T has expired, it will broadcast its message.

4.6. Dynamic Path Strategies [4]

With these strategies, it is possible to construct and update coverage routes that change over time.
CTP strategy: In order to establish and update network cost indicators, all sources broadcast BEACON messages regularly. The receiver will receive data from each node that chooses the next hop to reach it based on this data.

(ORW) strategy: When a node is first created, it exchanges discovery and recognition messages with its parent node. As a result of listening to the channel and calculating messages number it has heard, the node determines the quality of the connection. The node calculates the local link quality based on the messages number it has heard and the estimated value of the messages that are lost while listening to the data messages. Then the node sends this information to its neighbor's, and the neighbor's use it to make their own assessment of the connection quality. Then update its parent node according to the calculated link quality.

5. Simulation results

In order to test the algorithms on WBAN, they are implemented as part of the OMNet ++ simulator. In fact, OMNet ++ contains a number of modules that have been specially modeled for the WSN and WBAN [19]. The above strategies are highlighted under the realistic channel model described in [2]. In addition to the channel model shown in the section above, there is a protocol implementation available under Inet, in particular the media access control layer. We have adopted the implementation of IEEE 802.15.4. The basic information and parameters such as the sensitivity level and header length of the data packet are all taken from the 802.15.4 standard. The minimum sensitivity limit level to -60 dBm. If the channel attenuation and reception sensitivity are -100 dBm, these levels enable intermittent communication.

In order to compare the above-mentioned different convergent broadcasting strategies, the following three basic parameters are studied:

- End to end success rate: count the number of messages sent and received at the sink node.
- End to end delay: the average time a message takes to reach its destination.
- Number of sending and receiving: Energy consumption indicators of various nodes in the network. Since each node consumes an amount of energy for massage processing, then the energy consumption is related to the number of messages send and received at the node.

Table 2 shows comparison between average number of different strategies with different parameter.

Table 2: Comparison between average number for each Convergecast strategies.

protocol / parameter	End to end success rate	End to end delay	Number of transmissions and receptions
Attenuation-based strategies	57	0.43	51
Gossip-based strategies	70	0.31	75
Multi-path strategies	65	0.21	38
Hybrid strategies	73	0.25	29
CTP strategies	78	0.18	24
ORW strategies	54	039	31

5.1 End to end success rate

Figure 4 shows that the end-to-end success rate of the CTP strategy is higher than that of other strategies. The reason for this is that CTP dynamically selects the best next hop. The ORW strategy updates the network cost index by calculating the packet reception rate at each node so that its final success rate is lower compared to the CTP strategy. The end-to-end success rate of the hybrid strategy is very high. The success rate is highest among the three postures walking, running and lying. For other poses, it has a good end to end success rate.

The FloodToSink strategy is less influenced by irregular and static postures. It works very well in a static posture as shown in Figure 4 (F, C) sleeping and sitting postures. However, under conditions of high mobility, such as running posture (B), its performance deteriorates and a large number of data packets in the network are colluded and loss. With the ProbaCvg strategy, the P parameter of each transmission is divided by 2, which reduces the number of retransmission messages and message copies in the network. Compared to the FloodToSink strategy, the end-to-end success rate of the running posture Figure 4 (B) is higher.

In the PrunedCvg strategy, a node randomly forwards messages to other nodes. Compared with the FloodToSink strategy, the PrunedCvg strategy in Figure 4 (B, C) shows a higher ratio of walking to sitting. In principle, the message forwarding between different nodes is the same, which can prevent collisions and packet loss. Hence, a better end to end success rate is achieved.

APAP and APPP are superior to any attenuation-based gossip-based strategy. Compared with gossip-based strategies, it works best in a state of high mobility, while performance degrades in a static state because two paths to the sink node are selected first.

In most cases, the dampening-based strategy has the worst end to end success rate. Each of the three attenuation-based strategies has a result value that is close to one another. With the BothMinAtt strategy, the node sends messages to two neighbors to increase the likelihood of the convergence process being successful. However, the results show that this is ensured for some poses. In terms of WBAN requirements, the dynamic path strategy achieves the best end to end success rate compared to other strategies. The gossip-based strategy has a better end to end success rate than the multipath-based strategy. However, Hybrid shows a good end to end success rate in most cases as it combines a gossip-based strategy and a multipath-based strategy.

5.2 End to end delay

The end-to-end delay of different strategies for each posture is shown in Figure 5. Human posture has an impact on the delay of all strategies. In the mobile state, it takes less time for a message to reach a static node. The CTP strategy has very little end to end delay in most postures. It creates and updates the network cost index, and next hop to a receiver selected by each node based on the index. Hence, it has multiple paths to get the message reach the recipient in less time. The ORW strategy has the worst end to end latency. It takes a long time to update the network cost index.

In the hybrid strategy, it showed a reasonable end to end delay for all poses and it never has the highest end to end delay. The conclusion is that the hybrid strategy has flexibility and reliability for all positions. The gossip-based strategy shows high-end latency, especially of the running posture. The running position has the highest mobility. It enables data packets to be quickly exchanged between nodes until they are received by the sink node. Compared with the multi-path strategy (APAP and APPP), other strategies have a lot of packet loss, and the forwarded packet is only processed by the parent node.

Among multipath strategies, the lowest end to end delay is for APAP and APPP strategies. With both of these strategies, the source node uses a predefined path to forward the data packet to the recipient. The random selection between PPPP nodes increases the delay and the likelihood of packet loss. In the attenuation-based strategy, in order to forward or keep a message, a node needs certain information to decide. This increases the time it takes to route the message. Hence, in most poses, it has the highest end to end delay.

In terms of WBAN requirements, the end-to-end delay of the hybrid strategy is better compared to other strategies. The dynamic path strategy has the higher end to end delay because it relies on building a neighbor tree to send messages rather than spending a lot of time processing and sending messages. However, it consumes more energy than other strategies.

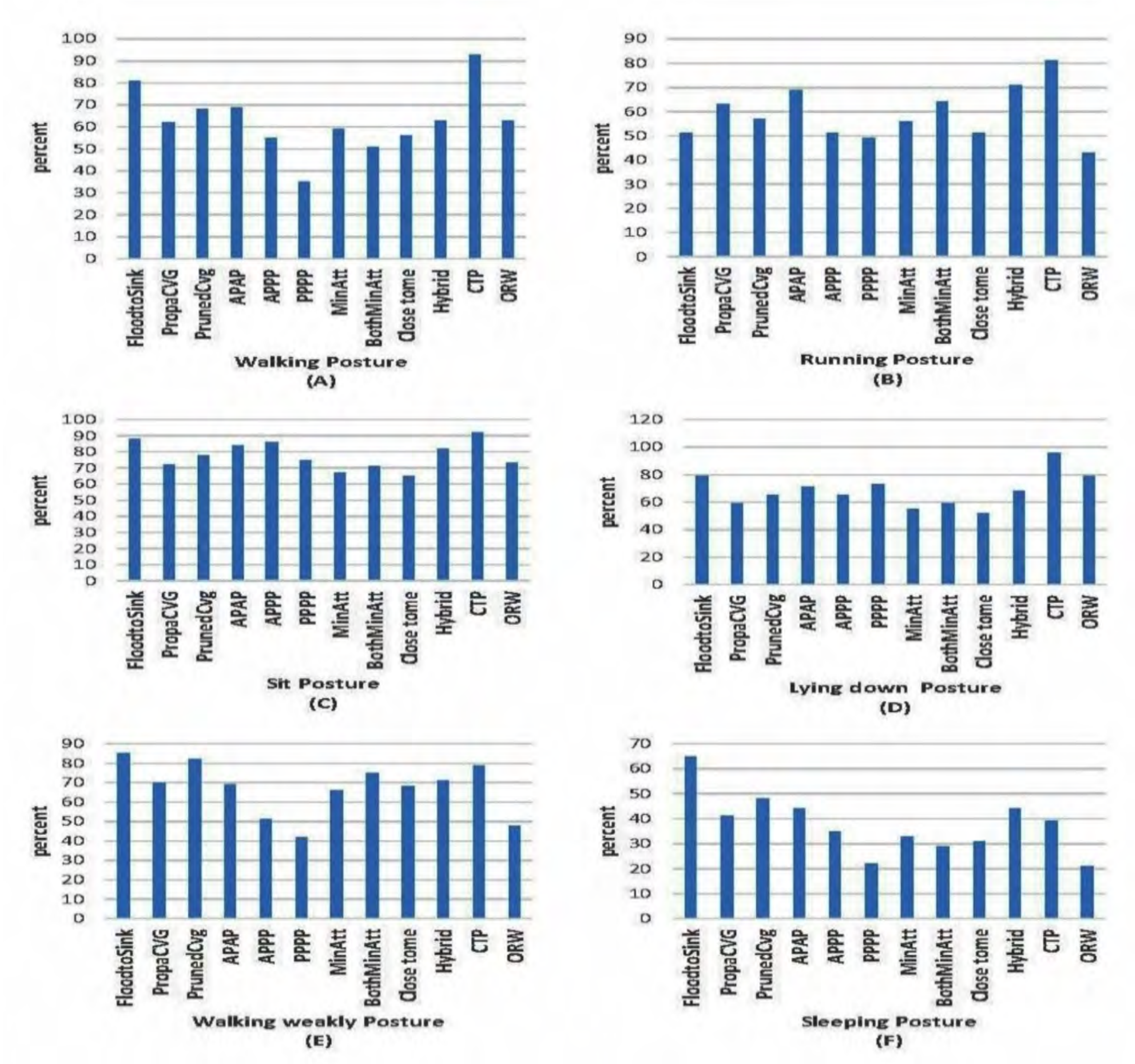

Fig.2 End to end success rate per posture. ((A) walking, (B) running, (C) sitting, (D) lying, (E) walking weakly, (F) sleeping).

5.3 Number of transmissions and receptions

The channel load is reflected in the number of transmissions and receipts and provides an indication of energy consumption. Figure 6 compares the number of messages sent and received per posture for each strategy. With CTP and ORW, the number of sending and receiving is appropriate. Whereas data packets are forwarded according to a predefined path. Therefore, it reduces the number of packets generated.

Multipath strategies that are also based on predefined paths perform similarly. Compared to other multipath strategies, the APAP strategy shows a large number of transmissions and receptions in all positions. Since it chooses two routes to reach the sink node. The hybrid strategy shows a fair amount of sending and receiving. It has lower transmission and reception than the gossip-based strategy, but still higher transmission and reception than the multipath strategy. With the Gossip-based strategy, FloodToSink does a lot of sending and receiving as the node sends every message it receives until the TTL is less than 1. The ProbaCvg strategy reduces this number due to the probability of sending P by dividing each message by 2 is shared. However, when it is compared to other strategies, the sitting and walking position Figure 6 (B, C) is still very high. Forward the packet only to a randomly selected next hop, which reduces the number of transmissions and receptions. BothMinAtt has the highest number of transmissions and receptions in all states, because the message is forwarded to two neighbours from each node.

In general, the dynamic path strategy offers the best number of transmissions and receptions because it is based on a dynamic predefined path. The hybrid strategy combines a multipath strategy with a gossip-based strategy. Hence, it gives the best results when compared with them and with the dynamic path strategy.

Table 3 discusses the pros and cons of each strategy.

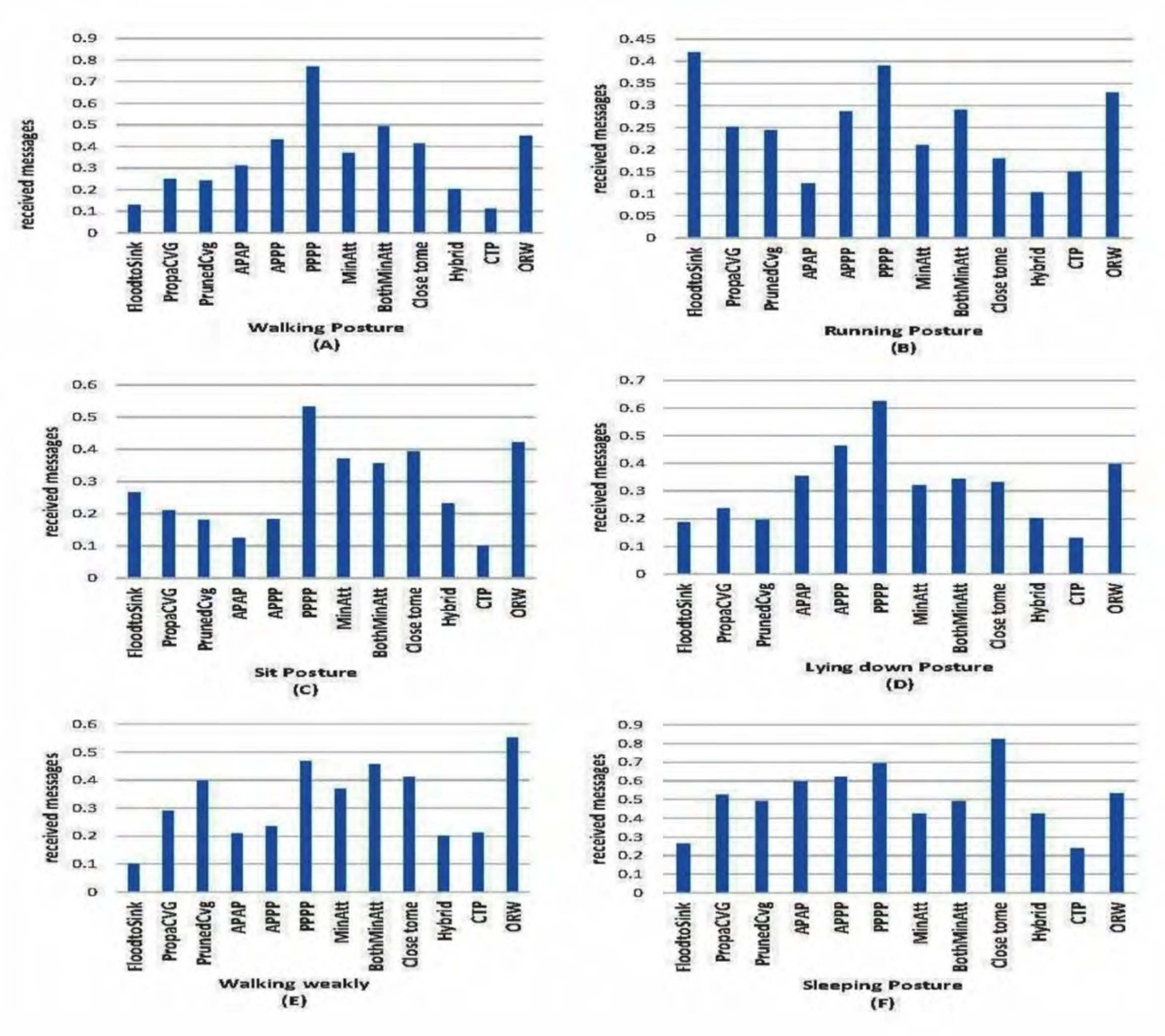

Fig 4: End to end delay per posture. ((A) walking, (B) running, (C) sitting, (D) lying, (E) walking weakly, (F) sleeping.)

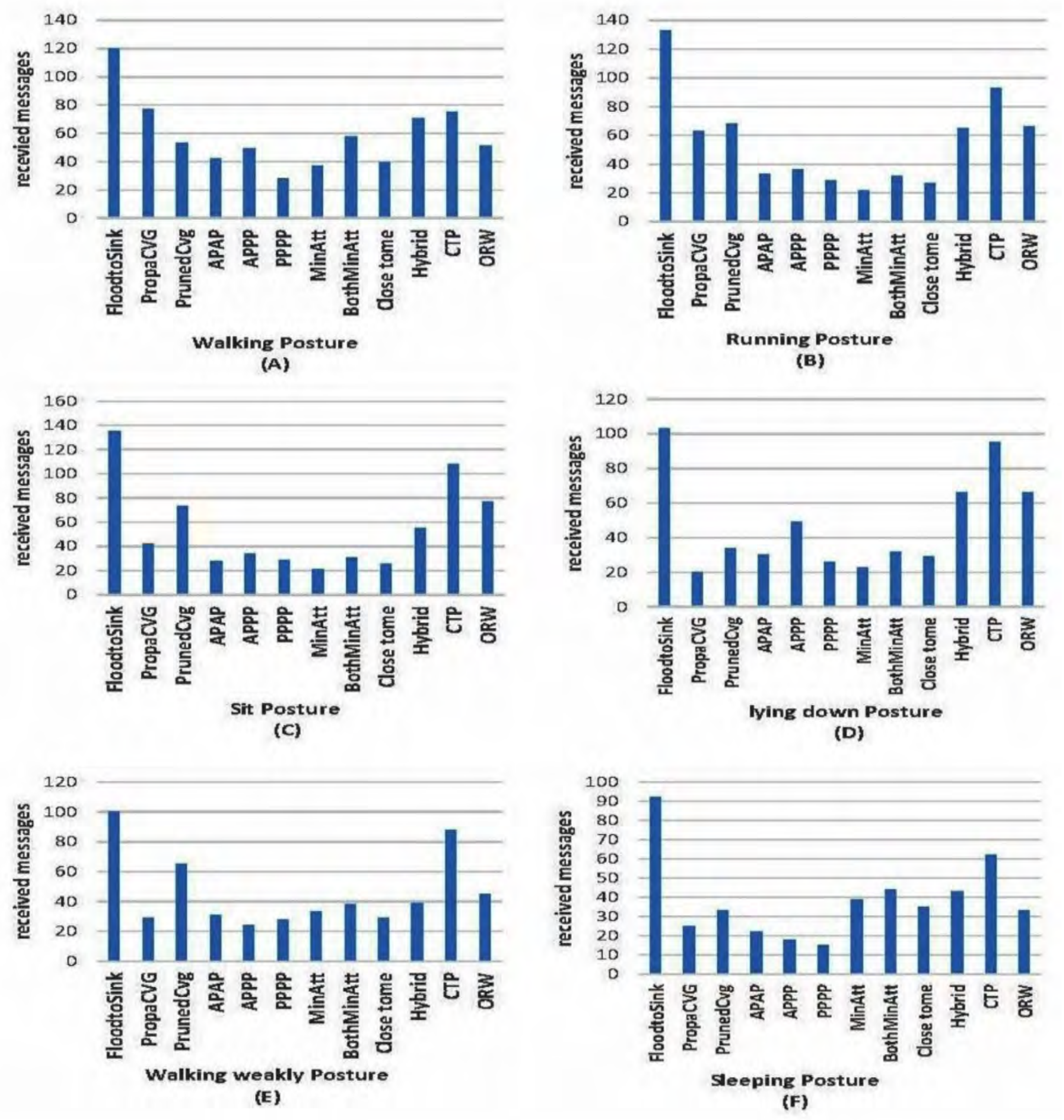

Fig.6: Number of transmissions and receptions per posture. ((A) walking, (B) running, (C) sitting, (D) lying, (E) walking weakly, (F) sleeping.)

Table 3: Advantage and Disadvantage of Convergecast strategies.

	advantage	disadvantage
Attenuation-based strategies	Low transmission and reception number.	End to end success rate based on attenuation strategy very low. The highest end to end delay in most poses. The BothMinAtt strategy has the largest number of transmissions in all attitudes.
Gossip-based strategies	Gossip-based strategy has a higher success rate from beginning to end. Lower end to end delay for APAP and APPP strategies. The ProbaCvg strategy reduces this number due to the probability that the transmission P will be divided by 2 for each message.	A running posture with high mobility (B) can cause collisions and packet loss. Random selection in the PPP node increases the time delay and packet loss of the receiver. A lot is being sent and received.
Multi-path strategies	Messages are forwarded equally between nodes to prevent collisions and packet loss. APAP and APPP are significantly better than attenuation strategies. Its performance is better than the gossip-based strategy in a high mobility attitude.	The performance is reduced in a static attitude for end-to-end success rate. Compared with other multi-path strategies, large number of transmissions and receptions for the APAP strategy shows a in all positions. Node in multipath strategies consumes the same power for each posture.
Hybrid strategies	In terms of walking, running, and lying postures, the hybrid strategy has the highest overall success rate. In general, it also has a good success rate in other postures. It has lower transmission and reception than Gossip-based strategies. Better performance in power consumption then dynamic Path Strategies.	Number of transmission and reception high then multi-path strategies.
CTP strategies	The CTP strategy has a higher success rate from beginning to end. The number of sending and receiving is reasonable.	More power consumption.
ORW strategies	The number of times it is sent and received is reasonable.	Worst end to end delay. It takes much time to update the network cost metric. Its success rate is lower than that of the CTP strategy.

6. Conclusion

In this work, various convergecast strategies proposed in WBAN are classified and examined in detail. These strategies manage the way in which nodes exchange the massage over network until reach to sink node. Convergecast strategy plays an important role in the energy efficiency and reliability design of WBAN. We have classified convergecast strategies in WBANs into attenuation-based, gossip-based, multipath, hybrid-based, and dynamic path strategies. These strategies have been implemented on omnet++ which contains modules specifically implemented for WBAN. The results show that the dynamic strategy has a better end to end success rate than other strategies in addition to the highest end to end delay, while consuming more energy. Compared to other strategies, the hybrid strategy has a better end to end delay. It shows a good end to end success rate in most attitudes as it combines of both gossip-based strategies and multipath-based strategies. Our research opens up several directions for the future. The first direction is to apply the best cross-layer technology from WSN [20] to WBAN. It will help to save more power at nodes. The second direction is to improve our strategy by combining it with the cross-layer technology recently developed for WBAN.

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