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# *Schéma Optimal basé sur la Preuve à Divulgation Nulle de Connaissance pour les Réseaux Wireless Body Area Networks (WBAN) <sup>†‡</sup>*

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Nous proposons BAN-GZKP qui optimise BANZKP (un schéma à divulgation nulle de connaissances spécifiquement adapté aux réseaux corporels (Wireless Body Area Networks)). BANZKP est vulnérable à certaines attaques de sécurité telles que l'attaque par rejeu, l'attaque par déni de services distribués (DDoS) et l'attaque par l'interception des informations redondantes. Etant donné que BANZKP demande une authentification de bout en bout, ce schéma n'est pas compatible avec la mobilité posturale du corps humain. Notre proposition, BAN-GZKP, améliore la sécurité et la tolérance à la mobilité posturale de BANZKP. Afin de corriger les vulnérabilités de BANZKP, BAN-GZKP utilise un mécanisme d'attribution de clés de cryptage aléatoires, sans coût supplémentaire en termes de mémoire, de complexité ou de consommation énergétique. En utilisant une authentification saut par saut, notre schéma BAN-GZKP devient tolérant à la mobilité posturale. Nous démontrons, par des simulations intensives, que BAN-GZKP améliore BANZKP en termes du taux de réception au niveau du sink (34.06%), du délai de bout en bout (36.02%) et du nombre de transmissions (14.11%) lorsque ce schéma est couplé à un protocole de convergecast. De plus, nous optimisons le schéma d'authentification du protocole originale qui nécessite cinq phases à un schéma utilisant uniquement trois phases tout en garantissant le même niveau de sécurité. Notre schéma devient donc optimal en nombre de phases.

**Mots-clés :** Wireless Body Area Network (WBAN), Sécurité mobile et sans fil, Analyse de la performance du réseau, Preuve à Divulgation Nulle de Connaissance

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## 1 Introduction

Wireless Body Area Networks (WBAN) is a kind of Wireless Sensors Networks (WSN). In WBAN, on-body sensors collect user's physiological Data and transmit them to a sink node. Sensors move with the human postural mobility, the network topology in WBAN therefore dynamically changes following the postural body mobility. Multi-hop WBAN communication proposed in [NWK<sup>+</sup>15] easily adapts to postural mobility. Also, multi-hop communications need lower transmission power compared to one-hop direct communication. WBAN is sensitive to security and privacy attacks : any medical Data error, leakage or imitation may lead to a wrong medical treatment, which is life or death. The challenges of WBAN security is that the computing and storage capacity is limited to achieve complex security protocol. Also, dynamic lossy connections in WBAN hinder the messages exchanging of security protocol. The best to date, the Zero Knowledge Proof-based scheme, BANZKP [CPBK16], is proposed, who uses less memory and computing capacity than TinyZKP [MGZ14] and the Elliptic Curve Encryption Based Public Key Authentication [WSTL11]. BANZKP is resilient to a wide range of attacks.

However, BANZKP still suffers from some specific malicious attacks. Moreover, the resilience of BANZKP to human body postural mobility in WBAN environment is still an open question. We propose BAN-GZKP, to fix vulnerabilities of BANZKP. Based on an extensive analysis and simulations, we show BAN-GZKP outperforms BANZKP in terms of security and WBAN environment adaptation.

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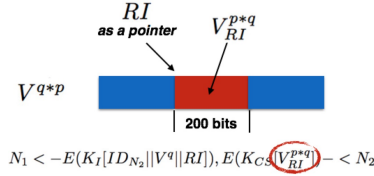


FIGURE 1: Representation of  $V_{RI}^{q*p}$

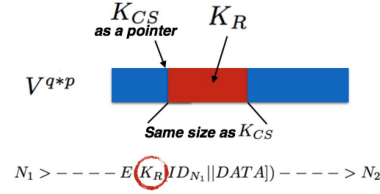


FIGURE 2: Representation of  $K_R$

## 2 BANZKP Analysis

The idea of BANZKP end-to-end authentication [CPBK16] is to make two authentication entities (source and the destination) agree with each other that they hold the same secret number. This number  $V$  and a shared key  $K_I$  are set manually by user at the beginning for all the legal nodes. When a node  $N_1$  wants to send Data to  $N_2$ , an authentication session is initiated as following :

- 1)  $N_1 > - - - - - E(K_I[ID_{N_1}||V^p]) - - - - - > N_2$
- 2)  $N_1 < - E(K_I[ID_{N_2}||V^q||RI]), E(K_{CS}[V_{RI}^{p*q}]) - < N_2$
- 3)  $N_1 > - - - - - E(K_I[ID_{N_1}||V_{RI}^{q*p}]) - - - - - > N_2$
- 4)  $N_1 < - - - - - K_{CS} - - - - - < N_2$
- 5)  $N_1 > - - - - - E(K_I[ID_{N_1}||Data]) - - - - - > N_2$

where  $ID_{N_1}$  and  $ID_{N_2}$  are identities of  $N_1$  and  $N_2$  respectively;  $V$  is the secret number needing to be authenticated by  $N_1$  and  $N_2$ ;  $p$  and  $q$  are two random values generated by  $N_1$  and  $N_2$ , respectively;  $K_I$  is a shared key between  $N_1$  and  $N_2$ ;  $K_{CS}$  is a random key generated by  $N_2$  and the function  $E(K[a])$  means encrypt  $a$  with key  $K$ .  $RI$  is the indicator of the beginning of an interval value of  $V^{q*p}$ , represented by  $V_{RI}^{q*p}$ . In BANZKP, the size of this interval is 200 bits (see Figure 1).

The main authentications mechanisms of BANZKP are that from the computations of among  $V$  and random  $q$  and  $p$ , and the messages exchanging, both  $N_1$  and  $N_2$  can get  $V^{q*p}$  without sending the secret number  $V$  to the network. Notice that instead of sending of the whole  $V^{q*p}$ , in BANZKP, nodes only chose a part of  $V^{q*p}$  of 200 bits,  $V_{RI}^{q*p}$  and a pointer,  $RI$ . From receiving the message 3),  $N_2$  can verify if the  $V_{RI}^{p*q}$  from  $N_1$  is the same then which it holds. If yes,  $N_2$  authenticated  $N_1$  and send the  $K_{CS}$  to  $N_1$  to decrypt  $V_{RI}^{p*q}$  sent in message 2). Then  $N_1$  can verify if  $N_2$  is legal node. By this way  $N_1$  and  $N_2$  can authenticate to each other. For the detailed descriptions of the authentication, please see [CPBK16].

BANZKP copes with the following attacks : **Forge Nodes**, **Replay Attack**, **Man in the Middle Attack**, **Guessing Attack** and **Privacy Attack** [CPBK16]. However BANZKP still suffers from same attacks : A constant  $K_I$  leads to the **Data Replay Attack** and **Redundancy Information Crack** and end-to-end authentication scheme leads to the **DDoS Attack at Sink**, please see [BPB17a] for details of attack scenarios and defect analysis.

## 3 BAN-GZKP

In order to tolerate Data Replay Attack, Redundancy Information Crack and DDoS attack at sink BAN-GZKP uses two ingredients : **Random Key Allocation** and **Hop-by-Hop authentication scheme**. Conceding the high dynamic and unstable WBAN connections, we further propose **exchanging Scheme Optimization** to reduce the number of the exchanging for each authentications session.

**Random Key Allocation** Data Replay Attack and Redundancy Information Crack are possible in BANZKP because a constant key  $K_I$  is used to encrypt all Data messages [BPB17a]. We give an effective Random Key Allocation mechanism for BANZKP.

The idea of the Random Key Allocation is as follows : when nodes authenticate, the value  $V^{q*p}$  will be obligatory computed for each authentication session. Since  $p$  and  $q$  are randomly chosen,  $V^{q*p}$  is also random. During the authentication message 4) in the original BANZKP,  $N_2$  will send the random session key to  $N_1$  to decrypt previous information. Notice that, even though  $K_{CS}$  is random, this key should not be

used to encrypt Data messages because it has been sent on clear text. Our idea is to use  $K_{CS}$  as a random pointer that will point to a bit in the binary representation of the random value  $V^{q*p}$ . Then we chose an interval in the binary representation of  $V^{q*p}$  that starts with the bit pointed by the random pointer  $K_{CS}$ . This interval, of length  $K_{CS}$  can be seen as a random key,  $K_R$ , to encrypt Data message for the current session (see Figure 2). Our Random Key Allocation does not require additional keys at the initialization and does not need the transmission of additional fields in the exchanging message.

**Hop-by-Hop Scheme** Note that Sink-Side DDoS Attack happens in the end-to-end authentication scheme because relay nodes cannot detect whether the authentication message is legal or not, only the sink can do [BPB17a]. To solve this problem and prevent Sink-Side DDoS Attack, we provide relay nodes with the capacity to detect invalid authentications.

The idea is as follows, instead of doing the authentication between the pair source-sink, we let source nodes to initiate authentication directly with their one-hop neighbours. After this authentication phase finishes with success, a source is allowed to send Data messages to the authenticated neighbour. The neighbour who receives Data messages can then initiate authentication with its neighbours until Data reaches to the sink. An adversary who wants to initiate a large number of invalid authentication requests to block the network will be detected directly by its one-hop neighbours and the DDoS Attack can thus be limited in a local range.

**Exchanging Scheme Optimization** When a source node  $N_1$  initiates authentication with another node  $N_2$  that previously authenticated with  $N_1$  and that recognizes the identity of  $N_1$ , then  $N_2$  instead of sending back  $E(K_I[ID_{N_2}||V^q||RI]), E(K_{CS}[V_{RI}^{p*q}])$ , where  $V_{RI}^{p*q}$  is encrypted with  $K_{CS}$  (as in original BANZKP scheme), it sends back directly  $V_{RI}^{p*q}$  encrypted with the initial key  $K_I$ . In our BAN-GZKP  $N_2$  needs just to send a random pointer  $R$  for the Random Key Allocation. Hence, the final message sent back to  $N_1$  is :  $E(K_I[ID_{N_2}||V^q||RI||R||V_{RI}^{p*q}])$ . After receiving the response of  $N_2$ ,  $N_1$  finishes the authentication using the same mechanism, and choses a random key,  $K_R$ , from the pointer  $R$  of Random Key Allocation and encrypt Data by  $K_R$  then sends the message to  $N_2$ . We thus can complete the authentication session after the first successful authentication between these two nodes. The scheme is as follows (we preserve the same notations as for the description of the BANZKP scheme) :

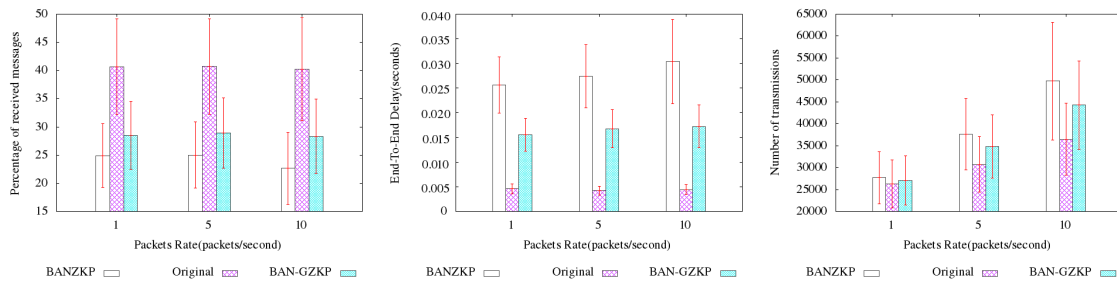
- 1)  $N_1 > \text{---} E(K_I[ID_{N_1}||V^p]) \text{---} > N_2$
- 2)  $N_1 < \text{---} E(K_I[ID_{N_2}||V^q||RI||R||V_{RI}^{p*q}]) \text{---} < N_2$
- 3)  $N_1 > \text{---} E(K_R[ID_{N_1}||DATA]) \text{---} > N_2$

Even though BAN-GZKP reduces the number of authentication messages it tolerates the attacks tolerated by BANZKP scheme and also Data Replay Attack and Redundancy Information Crack. Please see [BPB17a] for the proof details.

## 4 Performance Analysis

To compare the performance impact, we apply BANZKP and BAN-GZKP into five examples of five classes of convergecast strategies specified for WBAN from [BPB17b] : **All Parents to All Parents Strategy** (APAP), **Tree-based Strategy**, **Collection Tree Protocol** (CTP), **FloodToSink Strategy** and **Attenuation-based Strategy** (MiniAtt). Convergecast means the sink node collect data packets sent from others source nodes.

We use the physical model proposed in [NWK<sup>+</sup>15, BCPPB15]. This model issued from experiments with a network composed of seven sensors distributed on the body, six source nodes send Data, one sink node receives them. This model provide wireless channel attenuation information between each two nodes in seven different dynamic postures : 1) Walking, 2) Running 3) Walking weakly, 4) Sitting down, 5) Lying down, 6) Sleeping and 7) Wearing a jacket. In each posture, the model provide distributions of random wireless channel attenuation (on dB) between each two nodes. If the signal strength (on dBm) after passing the channel is smaller than the sensibility (on dBm) at the receiver, then the packet will be dropped. In this paper, we use the same simulation environment as in [BCPPB15] (IEEE 802.15.4) with a communication frequency of 2.45 GHz. The transmission power and the sensibility of the radio module of nodes are set



**FIGURE 3:** Reception Rates in Posture 1 Walking

**FIGURE 4:** Correct Order Rates in Posture 1 Walking

**FIGURE 5:** Correct Order Rates in Posture 1 Walking

to -60dBm and -100dBm respectively. We consider the following packet rates at the application layer : 1 packet/second, 5 packets/second and 10 packets/second, respectively.

Figure 3, 4 and 5 show the comparisons results of **ratios of Data packet reception at sink, end-to-end delay, number of transmissions** of CTP strategy in Posture 1 Walking. Due to the lack of space, please see [BPB17a] for others simulations results. In each figure, the red columns represent the original CTP strategies without applying any authentication scheme; the white columns represent original strategies applying BANZKP; and the blue columns original strategies applying BAN-GZKP. When applying authentication scheme, WBAN performance decreases in general : lower ratio of packets reception, higher end-to-end delay and number of the transmissions, due to the additional ZKP authentication scheme added to the original one. When focusing on the comparison between BANZKP and BAN-GZKP, we noticed that BAN-GZKP has higher ratio of reception, lower end-to-end delay and number of transmissions. In conclusion, BAN-GZKP outperforms BANZKP by 34.06%, 36.02% and 14.11% in terms of ratios of Data packet reception at sink, end-to-end delay and number of transmissions, respectively.

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