Oregon State University

The Need, Advances and Challenges Related to Wireless Body Area Network Communications Technology

Richard Kramer and Jin Phyo ("JP") Rhee
Oregon State University

What is a hero?

noun, **plural** **heroes;** for 5 also **heros.**

1. a person noted for courageous acts or nobility of character:
   He became a local hero when he saved the drowning child.

But saving lives is not just for ambulance drivers and firemen

Engineers can be heroes too!

Imagine if YOU could create something to save hundreds of thousands of lives!

[Photo: https://breakingmuscle.com/view-image?src=images/bydate/20130627/shutterstock13753315.jpg]
[http://www.dictionary.com/browse/hero]

Some facts…

Did you know that in the U.S. alone [1]:

- Every year, 800,000 people have a stroke
- One person every 4 minutes dies of a stroke
- Once a stroke happens, the person's life is likely changed forever
- Stokes are the #1 cause of disability

Some good news:

80 percent of stokes are preventable through the use of technology!

[Photo: https://breakingmuscle.com/view-image?src=images/bydate/20130627/shutterstock13753315.jpg]
[http://www.dictionary.com/browse/hero]

Oregon State University

The Need, Advances and Challenges Related to Wireless Body Area Network Communications Technology

Richard Kramer and Jin Phyo ("JP") Rhee
Oregon State University

Motivation - *technology with a purpose*

Wireless Body Area Network (WBAN) body sensors is an emerging technology area of research

…that can detect life threatening situations ***before the they happen***

Agenda

Introduction:

- What are WBAN body sensors?
- What is WBAN wireless technology?
- What are the problems?

Core areas of our research:

- Optimization of transmitter power to conserve battery energy
- Performance improvements for WBANs under interference
- WBAN security

Conclusion

Agenda

Introduction:

- What are WBAN body sensors?
- What is WBAN wireless technology?
- What are the problems?

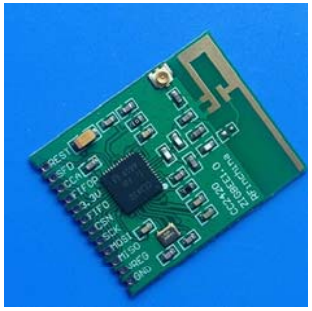
Core areas of our research:

- Optimization of transmitter power to conserve battery energy
- Performance improvement for WBANs under interference
- WBAN security

Conclusion

What are WBAN body sensors?

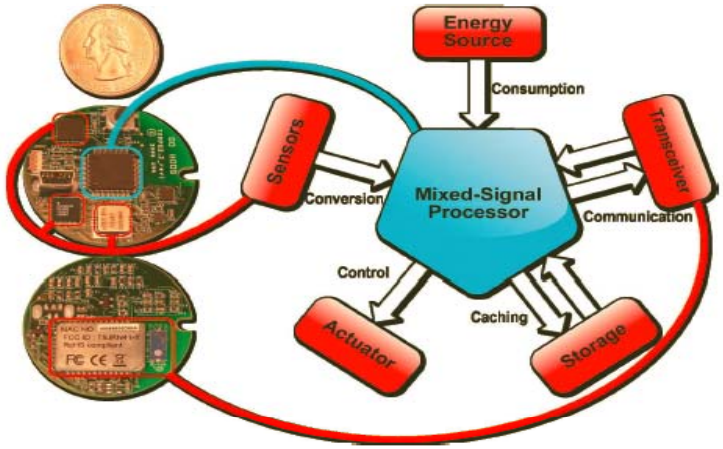
Wireless Body Area Network (WBAN) body sensors are small devices that monitor and control a person's physical health



CC2420 wireless module [10]

Wireless Body Area Network (WBAN) body sensors include:

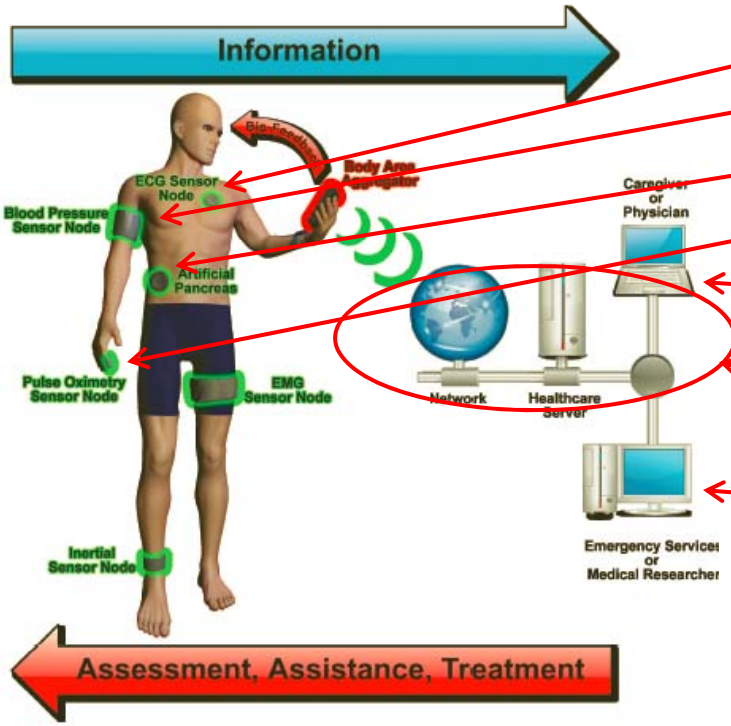
- Microcontroller and memory circuitry
- Sensors for monitoring
- Actuators for controlling
- An energy source, like a lithium battery
- ***A <u>wireless</u> WBAN transceiver***



WBAN node architecture [4]

What are WBAN body sensors?

Wireless Body Area Network (WBAN) sensors can monitor a wide variety of vital signs and communicate potential emergencies



Sensors
- EKG / ECG (heartbeat)
- Blood pressure
- Blood sugar level
- Blood oxygen

Heath care assessment and doctors

Communications

Emergency response

[4]

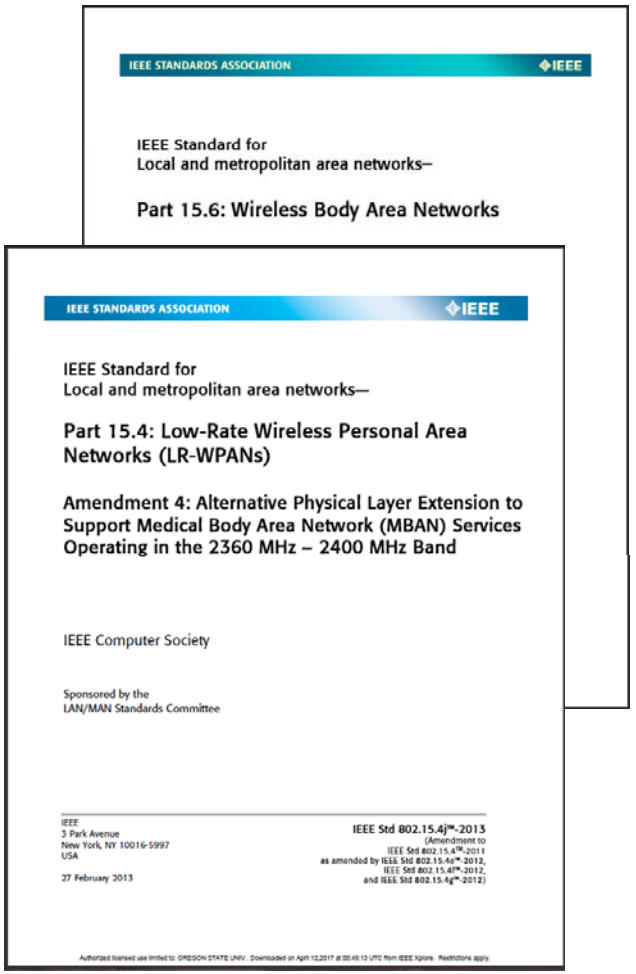
What is WBAN wireless technology?

The WBAN standard was first introduced in ***draft*** form in 2010 as IEEE standard 802.15.6 [5]

IEEE 802.15.6 was not ratified until in 2012 [3]

The charter of 802.15.6 is stated to be: ***"Short-range, wireless communications in the vicinity of, or inside a human body"*** [3].

It was further standardized in the IEEE standard 802.15.4j (amendment 4) in 2013 [6]



Oregon State University

What are the problems?

Communicating inside a moving body at low power presents a significant number of problems

First, the devices are often **implantable**, making the combination of energy consumption AND reliable communications a challenge

- *Thus our focus on:* ***Optimization of transmitter power to conserve battery energy***

Second, IEEE 802.15.6 is in **the same** ISM (Instrument, Science and Medical) band as 802.11, yet IEEE 802.15 medical devices transmit at much lower power

- Thus our focus on: ***Performance Improvements for WBANs under interference***

Last, imagine if an adversary was able to **intercept** someone's WBAN data, or worst yet, **take over** their WBAN device.

- Thus our focus on: ***WBAN security***

Agenda

Introduction:

- What are WBAN body sensors?
- What is WBAN wireless technology?
- What are the problems?

Core areas of our research:

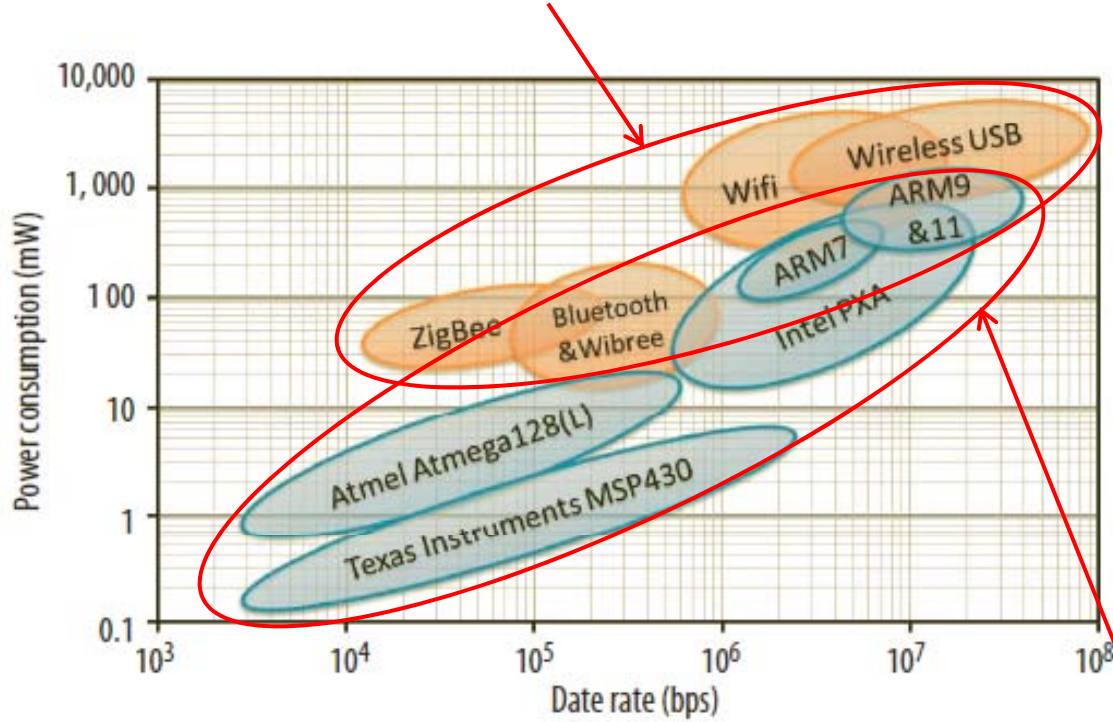
- Optimization of transmitter power to conserve battery energy
- Performance improvement for WBANs under interference
- WBAN security

Conclusion

Why is optimization of transmitter power so important?

FACT: The wireless transceiver uses significantly more power than the processing system [4]

Wireless transceiver power consumption (orange)



WBAN sensor average power consumption [4]

Microprocessor power consumption (blue)

[4]

WBAN power usage optimization discussion

The optimization of WBAN transmitter power usage is a **very active area of research -** many schemes have been proposed including:

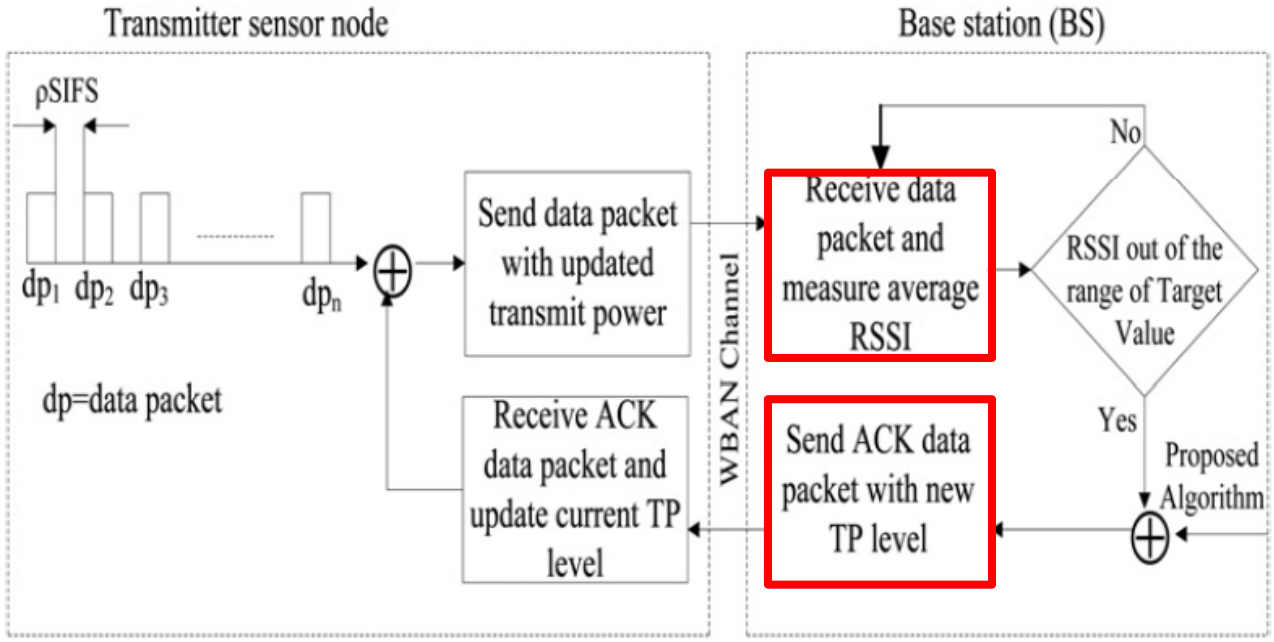
1. Adaptive Transmit Power Control (ATPC)
2. Intelligent ATPC algorithms
3. Transmission Time Adaption

[4]

Adaptive Transmit Power Control (ATPC) implementation

Many ATPC schemes have been devised to improve power usage [7]

- The schemes commonalities are: The schemes **correlate RSSI (Receive Signal Strength Indication)** with other data inputs
- Often times the schemes are based on what is **best for the receiver**



Typical RSSI based ATPC implementation [7] [4]

Intelligent ATPC algorithms

Unique ATPC algorithms have been devised, that, for example:

- Characterize the RF channel based on elaborate measurements, such as, fade margin rather than just RSSI
- The schemes have impressively even applied machine learning /Markov processes to adapt to channel impairments proactively

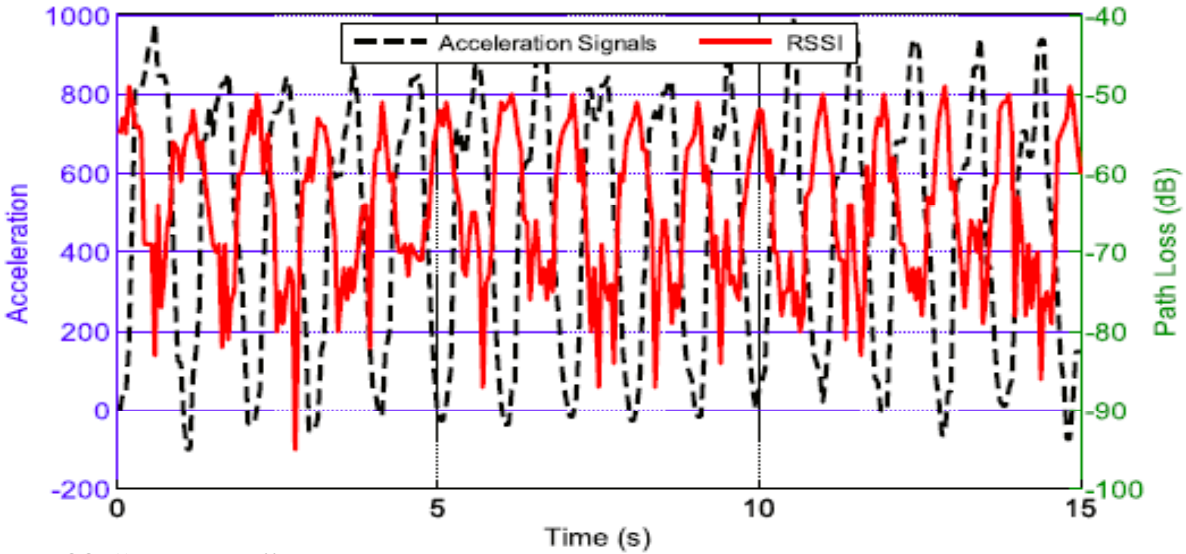
1: Initialization: $\rho = 1dB$, $THR_L = 2dB$, $THR_H = 4dB$, $\theta = 3dB$, $K = 10$ and $\delta = 2dB$
2: $\mu(0) = 3dB$
3: **for** each superframe n **do**
4: **if** $\sqrt{\widehat{MSE}(n)} > \mu(n-1) - THR_L$ **then**
5: $\mu(n) = \mu(n-1) + \rho$
6: **else if** $\mu(n-1) > THR_{min}$ **and** $\sqrt{\widehat{MSE}(n)} < \mu(n-1) - THR_H$ **then**
7: $\mu(n) = \mu(n-1) - \rho$
8: **end if**
9: **if** last data frame lost (no ACK) **then**
10: $\mu(n) = \mu(n-1) + \theta$
11: **end if**
THR_{min} Optimization
12: **if** $(\sqrt{\widehat{MSE}(n)} < \delta)$ **and** (ACK received successfully) **then**
13: $THR_{min} = THR_{min} - \rho/K$
14: **else if** $(\sqrt{\widehat{MSE}(n)} < \delta)$ **and** (No ACK received) **then**
15: $THR_{min} = THR_{min} + \rho$
16: **end if**
17: **end for**

Adaptive fade margin estimator [8]

Transmission time adaption

One promising piece of research has focused on **small scale fading to** transmit between steps based on the use of an accelerometer

FACT: Quick running motion = 45 dB of path loss with a Tc (channel coherence time) = 23-66 ms for running and 36-73 ms for walking [14]

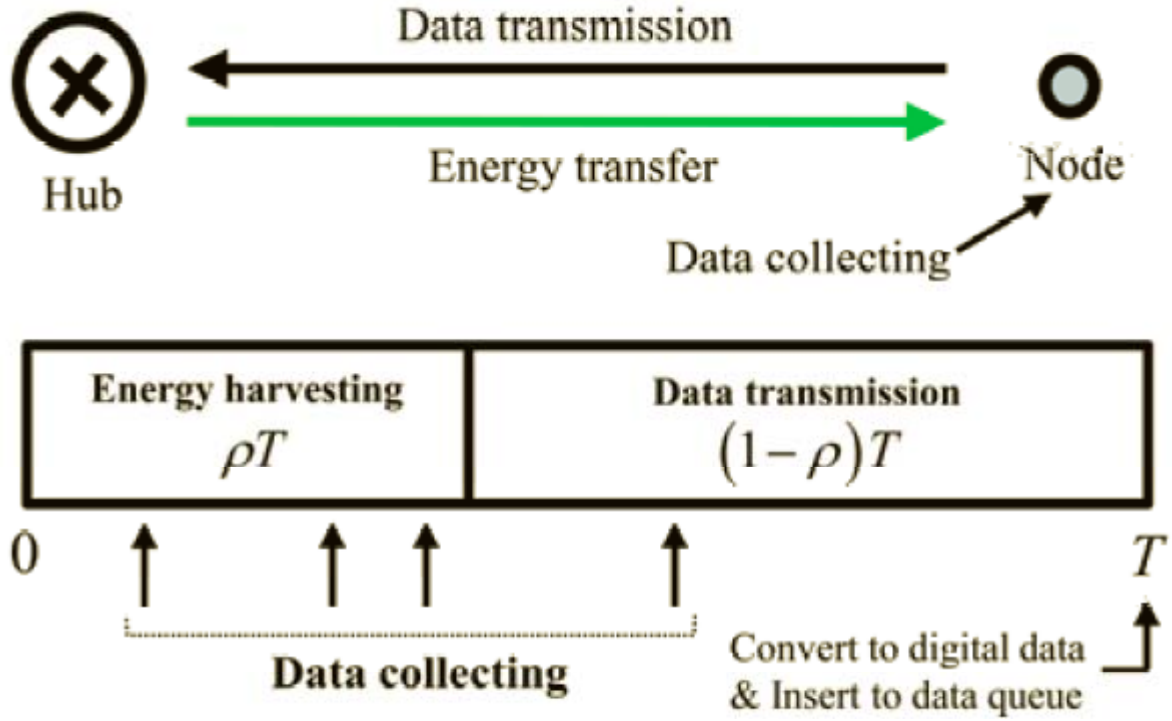


RSSI "path loss" versus body movement as measured by an accelerometer [16]

The above solution provides a **10%** improvement in transceiver power consumption

Transmission time adaption

Other interesting research has focused on **monitoring the battery level to decide when to transmit, while using chemical processes / heat exchange / etc. and the like to charge the battery source during non-transmit times**



Adaptive time splitting between energy harvesting and data transmission [17]

Proposed improvements

It is our belief that the focus on transmit power per bit **is misplaced**

- **We could not locate any research** that directly correlated the control of transmit power (via RSSI as seen by the receiver) as being the most efficient method to conserver battery energy
- We proposed an improved method: ***optimization of battery energy per bit***

Consider the following scenarios:

Scenario 1:

$$Bit\ rate:\ 100\ kbps$$

$$\frac{Error\ rate}{Bit\ rate} = \frac{50\ kbps}{100\ kbps} = 0.5$$

$$Bits\ recieved = (100 - 50) = 50\ kbps$$

$$Tx\ Power = 50\ mW$$

$$\frac{Bits\ received}{Tx\ Power \cdot time} = \frac{50\ kbps}{50mW \cdot s} = 1.0\frac{kb}{mW}$$

Scenario 2:

$$Bit\ rate:\ 100\ kbps$$

$$\frac{Error\ rate}{Bit\ rate} = \frac{30\ kbps}{100\ kbps} = 0.3$$

$$Bits\ recieved = (100 - 30) = 70\ kbps$$

$$Tx\ Power = 60\ mW$$

$$\frac{Bits\ received}{Tx\ Power \cdot time} = \frac{70\ kbps}{60mW \cdot s} = 1.2\frac{kb}{mW}$$

?

Which is better?

Proposed improvements

Now let's consider ***the battery energy per bit***…

Which is better?

Scenario 1 (revisited):

$$Battery\ power\ @\ 50\ mW\ Tx\ Power = 75\ mW\ (battery\ power)$$

$$\frac{Bits\ received}{Battery\ Power\ \cdot\ time} = \frac{50\ kbps}{75mW \cdot s} = 0.67\frac{kb}{mW}$$

!

Scenario 2 (revisited):

$$Battery\ power\ @\ 60\ mW\ Tx\ Power = 100\ mW\ (battery\ power)$$

$$\frac{Bits\ received}{Battery\ Power\ \cdot\ time} = \frac{70\ kbps}{100mW \cdot s} = 0.6\frac{kb}{mW}$$

Agenda

Introduction:

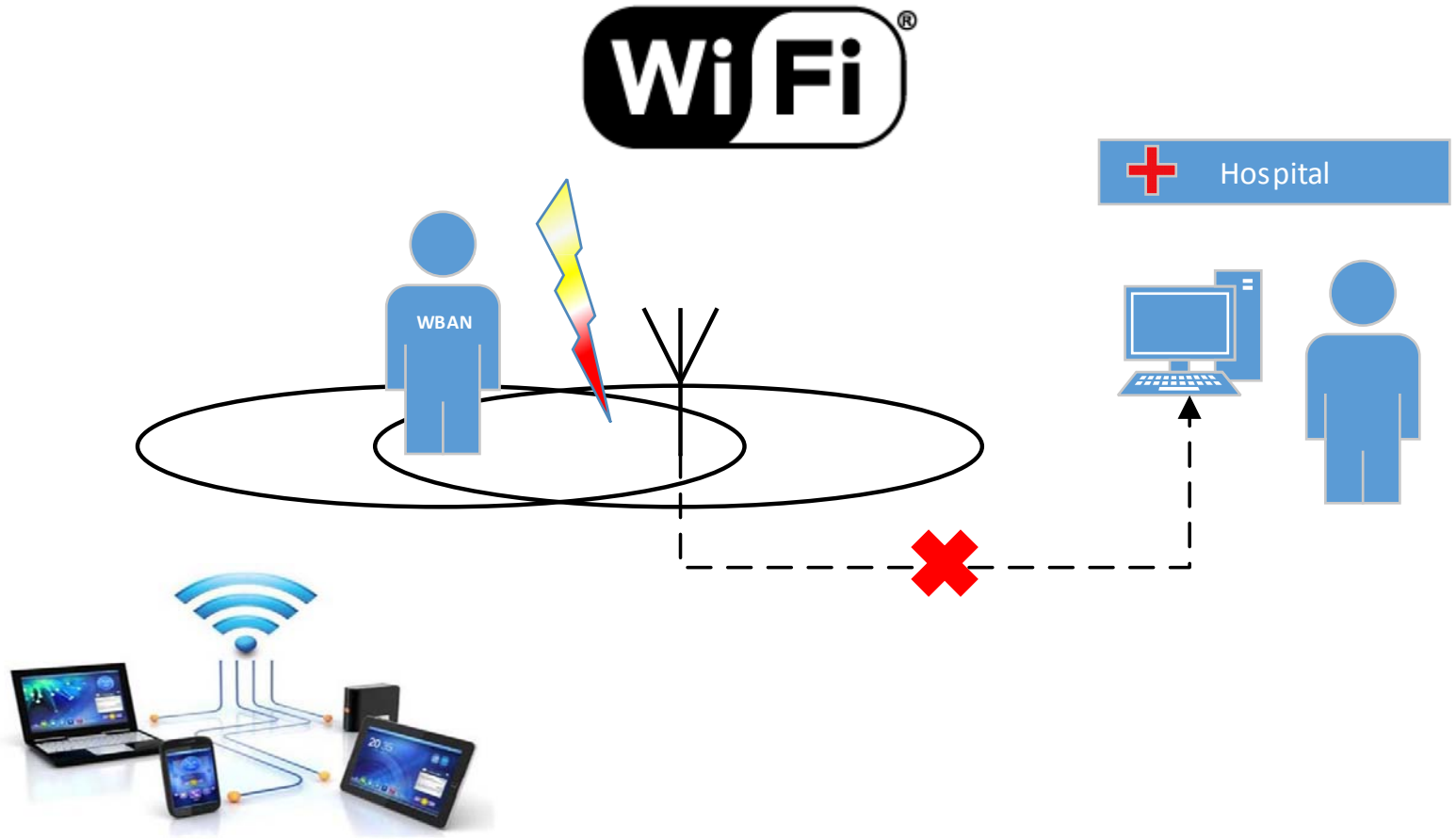
- What are WBAN body sensors?
- What is WBAN wireless technology?
- What are the problems?

Core areas of our research:

- Optimization of transmitter power to conserve battery energy
- Performance improvement for WBANs under interference
- WBAN security

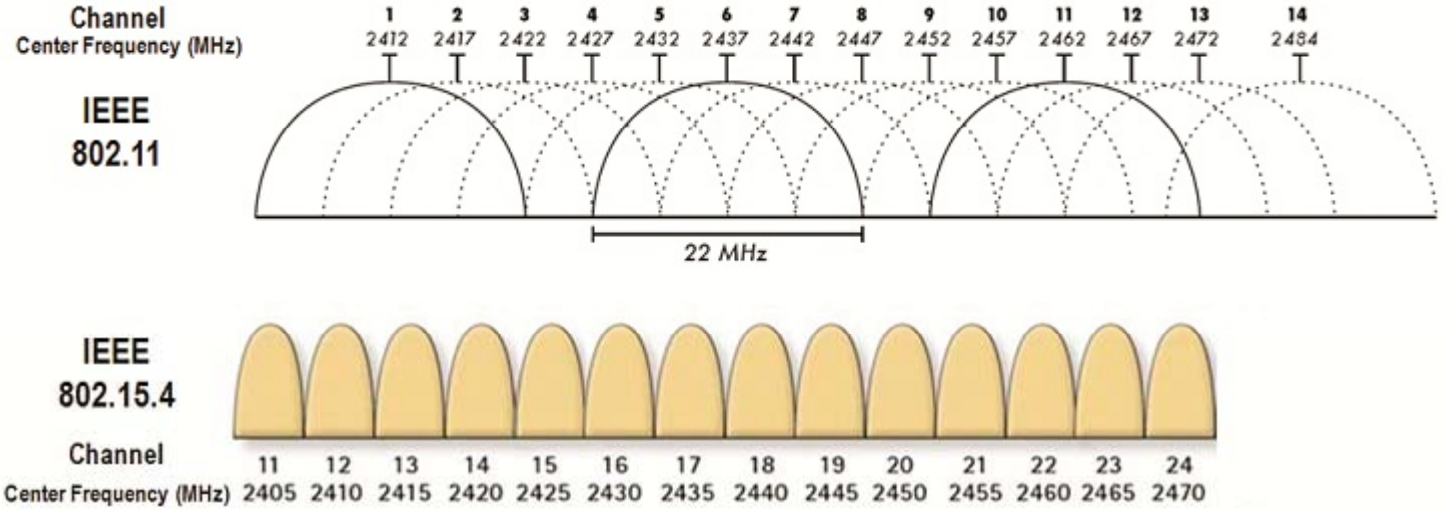
Conclusion

WBAN under interference with Wi-Fi



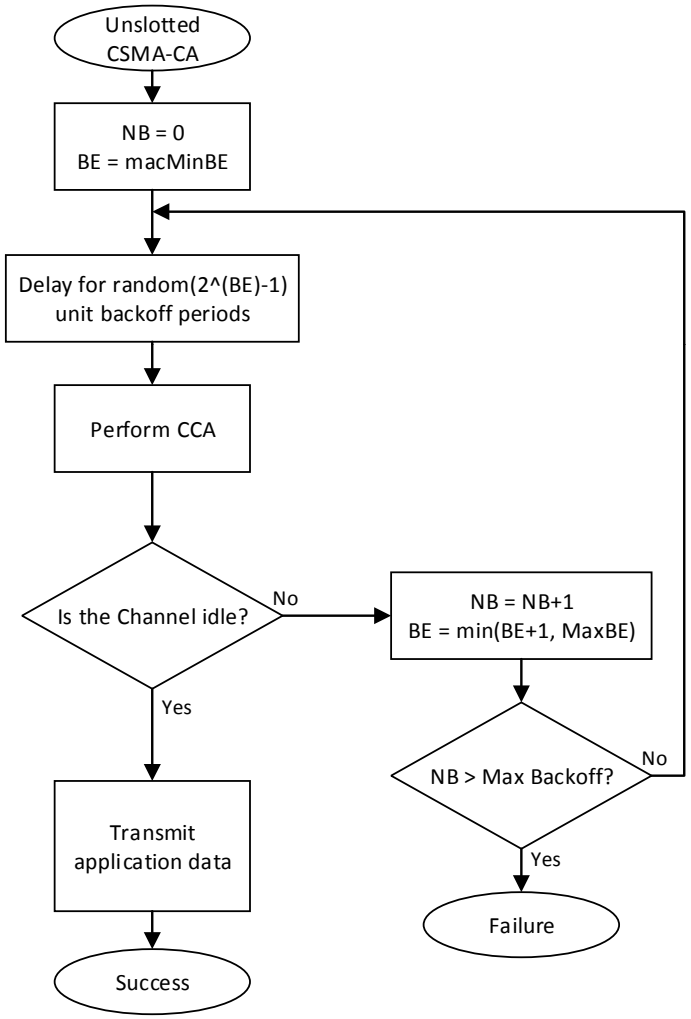
http://www.wi-fi.org/
http://www.dostifun.com/allow-only-selected-device-to-connect-to-wifi-network/

WBAN under interference with Wi-Fi



http://www.ni.com/white-paper/10789/en/

WBAN under interference with Wi-Fi



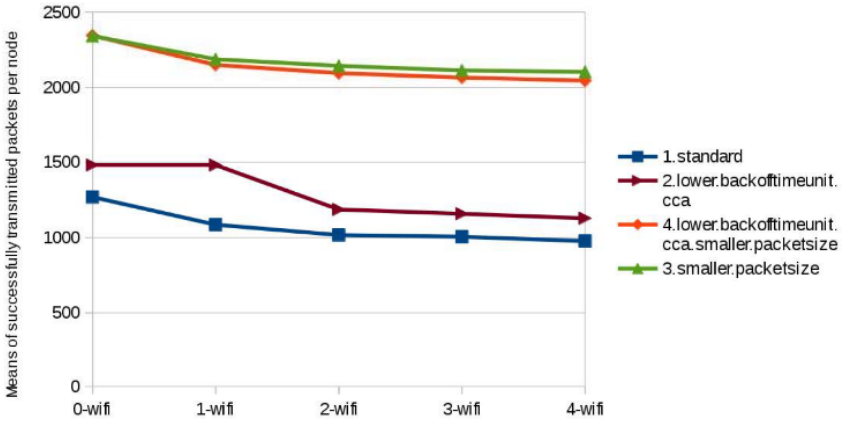
To find:

- Best packet size
- Backoff time
- CCA (Clear Channel Assessment)

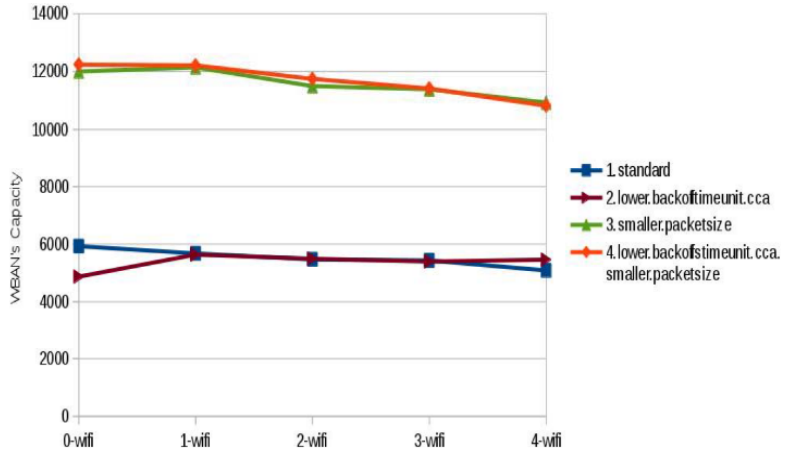
	Packet size	Backoff time	CCA
Test 1	512 bits	320 us	128 us
Test 2	512 bits	160 us	64 us
Test 3	128 bits	320 us	128 us
Test 4	128 bits	160 us	64 us

WBAN parameter setup

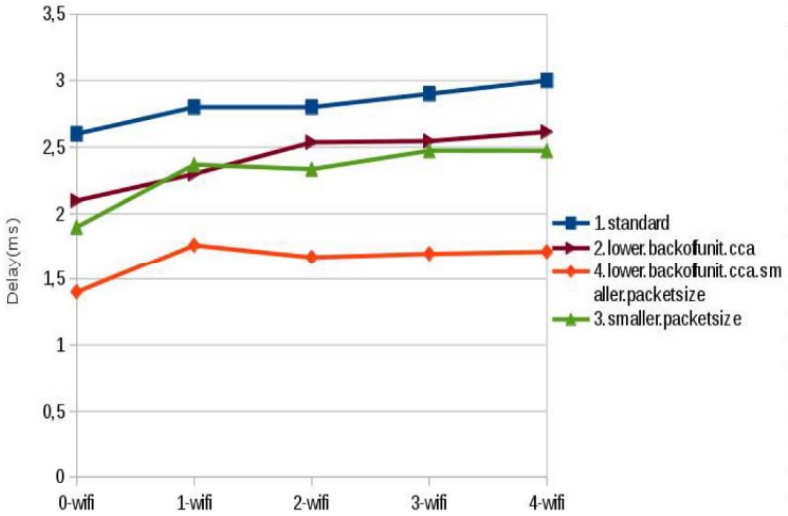
WBAN under interference with Wi-Fi



The average number of successful transmitted packet per node [24]



The average capacity in receiving packets in the WBAN's node [24]

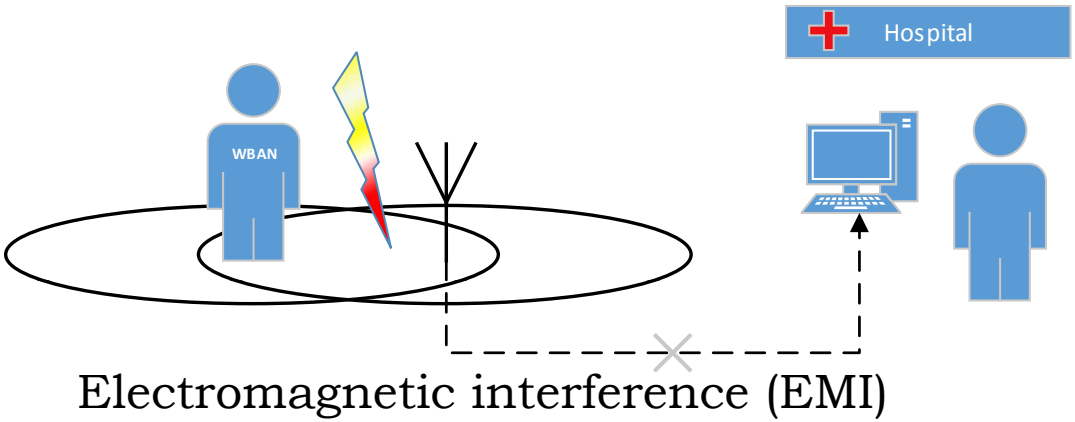


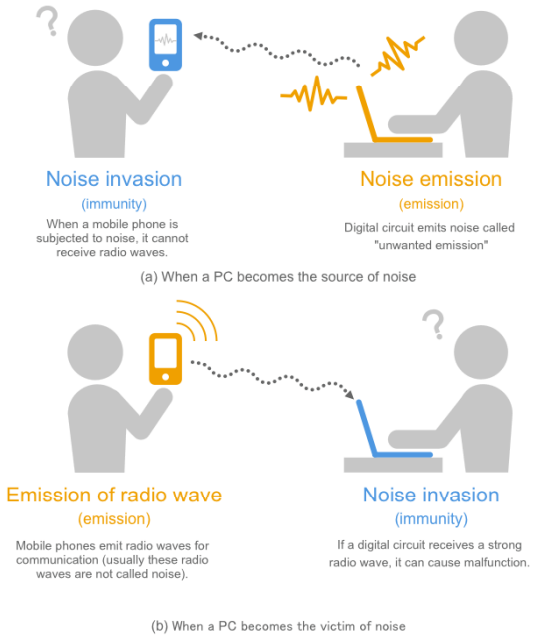
Packet's delay [24]

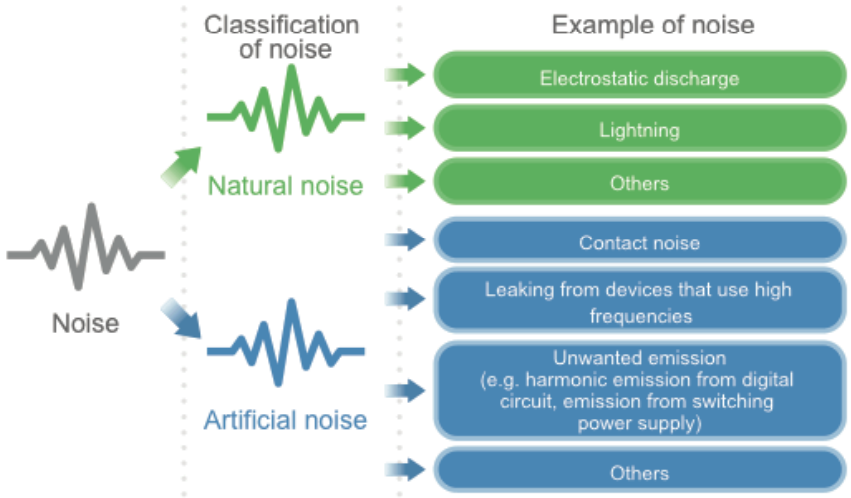
	Packet size	Backoff time	CCA
Test 1	512 bits	320 us	128 us
Test 2	512 bits	160 us	64 us
Test 3	128 bits	320 us	128 us
Test 4	**128 bits**	**160 us**	**64 us**

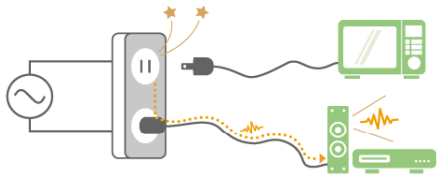
WBAN parameter setup

WBAN under interference with EMI



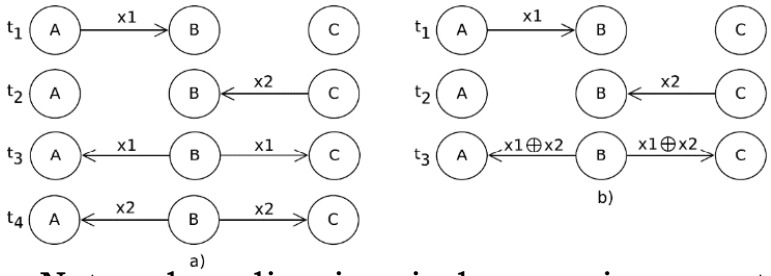






http://www.murata.com/en-us/products/emc/emifil/knowhow/basic/chapter02-p1

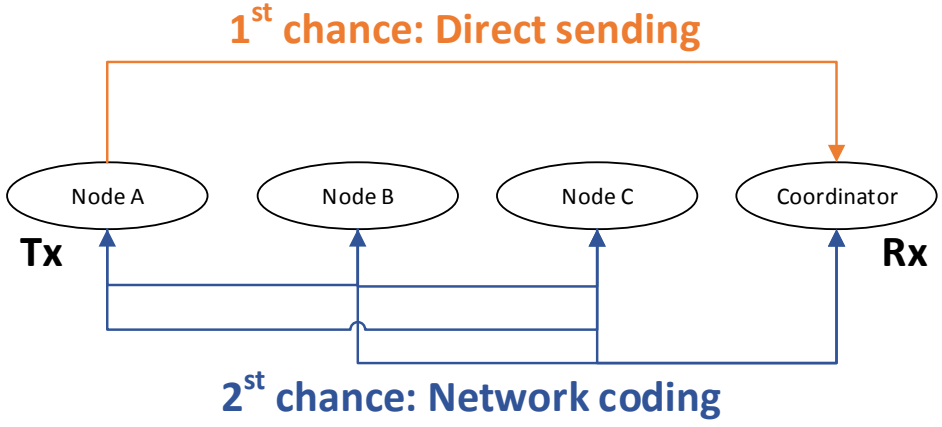
WBAN under interference with EMI



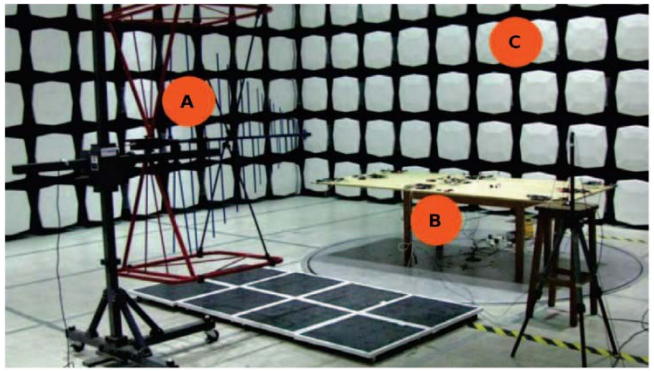
Network coding in wireless environment [29]

```
1  For ever do
2      Coordinator determines the number of relays based on the PER,
3      Determines the set of relay based on the RSSI of each node and
       Transmit information to the beacon payload
4      foreach node in the network do
5          Receives the beacon information
6          Waits its reserved slot and transmits its message
7      End
8      foreach relay node in the network do
9          Overhears the messages from neighbors, encodes them,
10         Waits its reserved slot and transmits its message
11     end
12     Coordinator receives messages from nodes and relay nodes,
13     Solves the linear system,
14     Estimates the network PER and the values of node's RSSI
15 end
```

Transmission algorithm

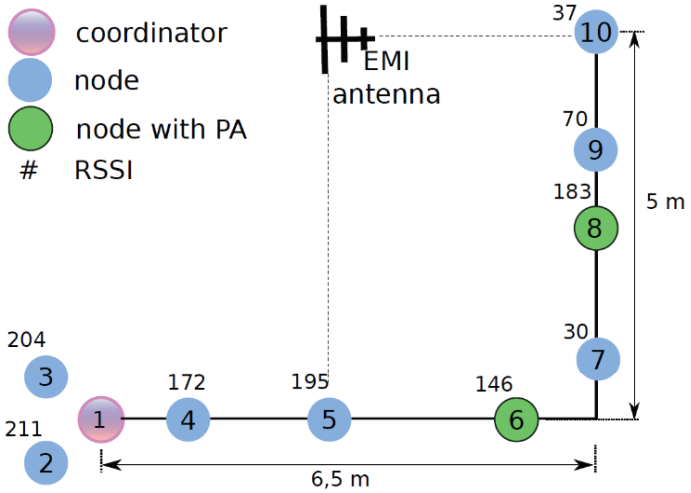


WBAN under interference with EMI



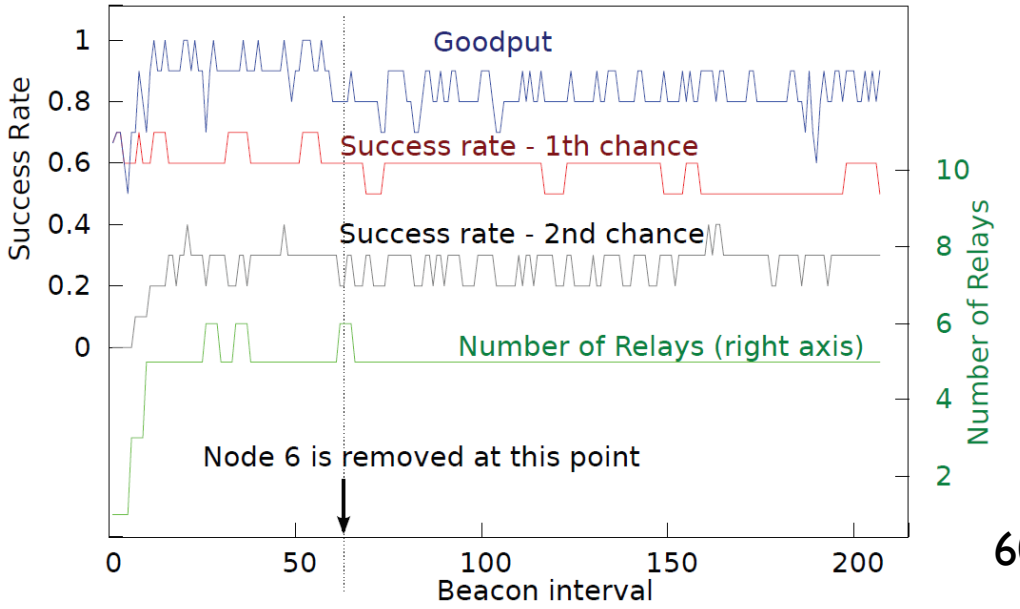
(A)	EMI generator	AM/FM noise, 2.425 GHz (Channel 15 of 802.15.4)
(B)	WBAN on a table	10 WBAN nodes, ATmega256RFR2
(C)	Chamber	Testing area

Testing setup [29]



Monitored area setup [29]

WBAN under interference with EMI



Success rate and number of relays [29]

1th chance: 60%

2th chance: recover ¾ of the undelivered message

60% Success rate

=> 80%~90% Success rate

Agenda

Introduction:

- What are WBAN body sensors?
- What is WBAN wireless technology?
- What are the problems?

Core areas of our research:

- Optimization of transmitter power to conserve battery energy
- Performance improvement for WBANs under interference
- WBAN security

Conclusion

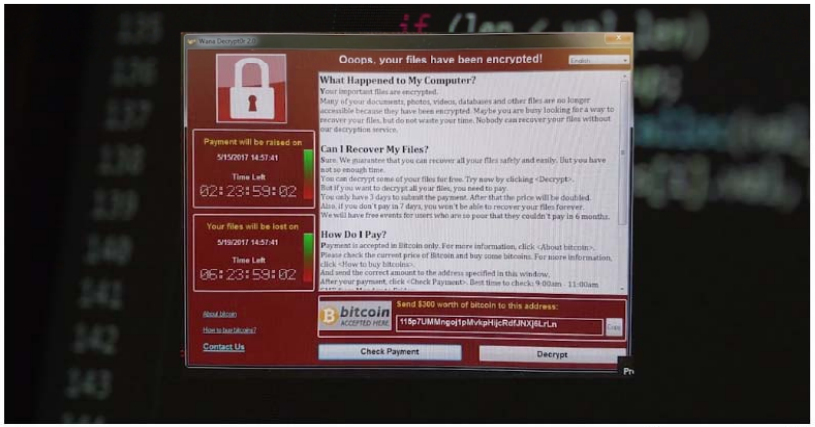
WBAN and Security

CNN tech business culture gadgets future startups

Why hospitals are so vulnerable to ransomware attacks

by Selena Larson @selenalarson

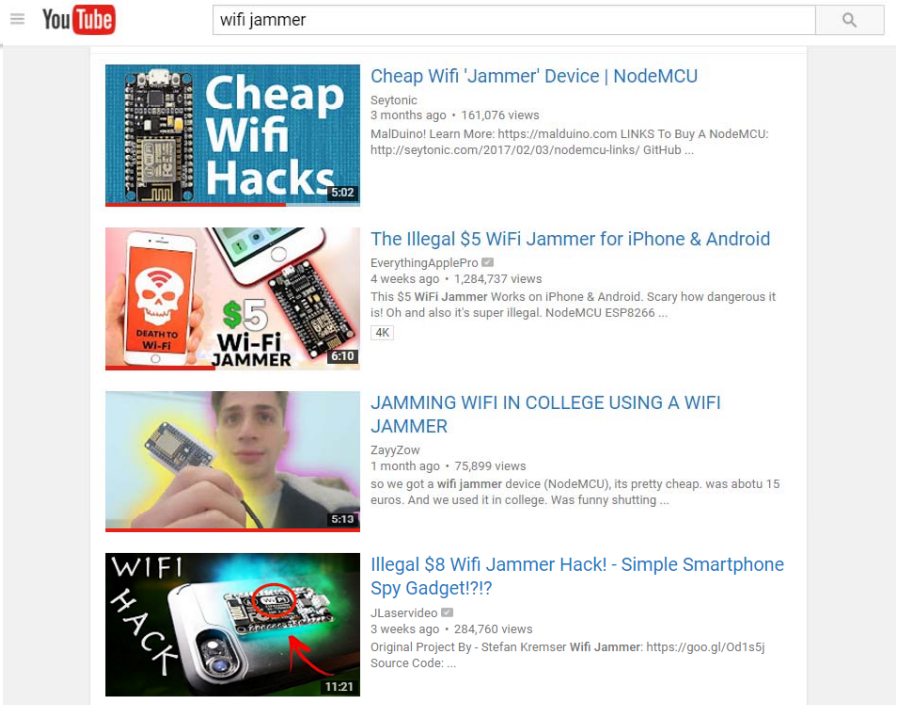
May 16, 2017: 1:46 PM ET



These are the victims of a ransomware cyberattack

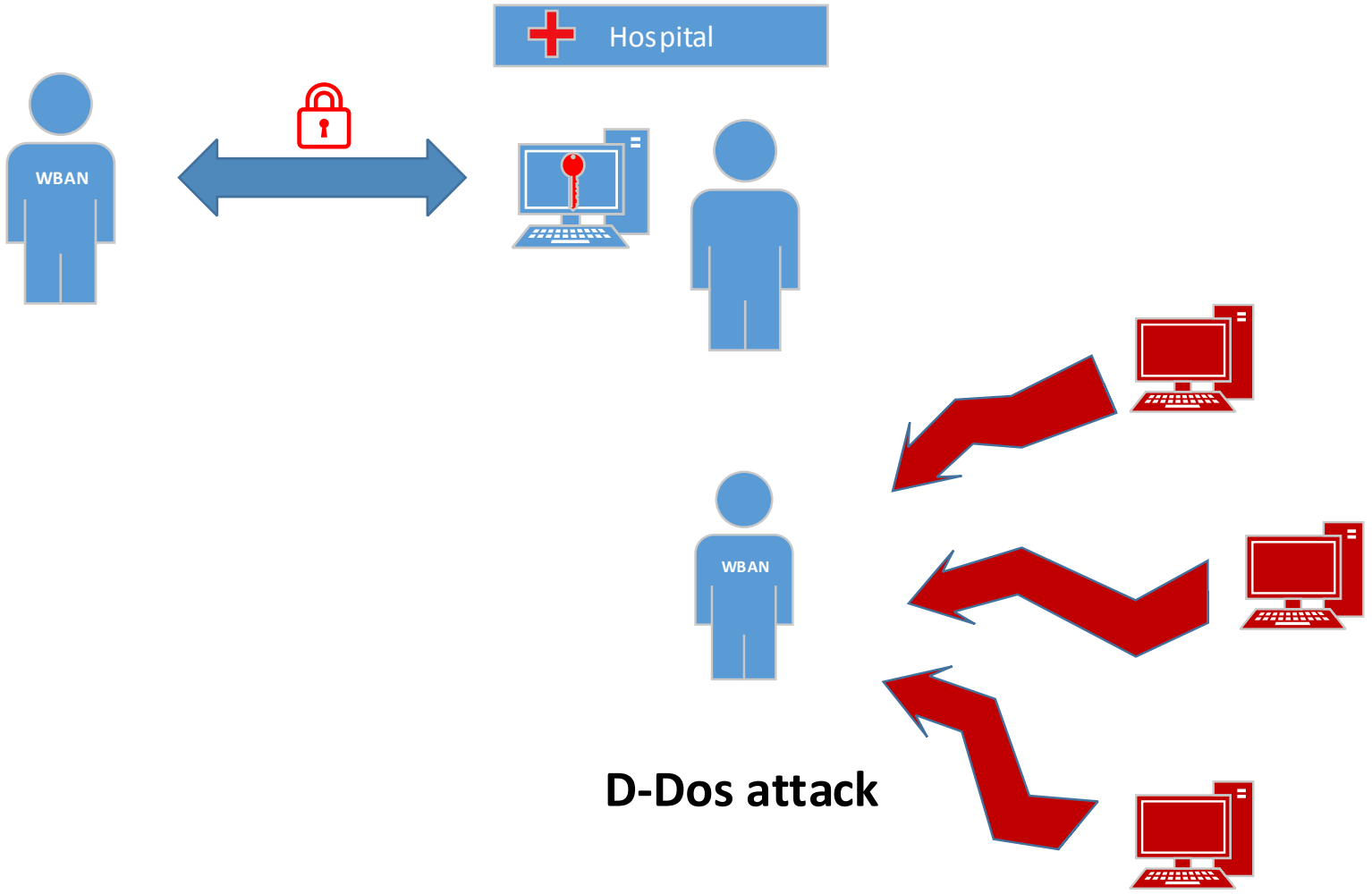
A computer virus could put people in mortal danger if the target is healthcare facilities.

The WannaCry ransomware that targeted around 300,000 machines in 150 countries first came on the public radar when 48 U.K. medical facilities were infected by the virus.

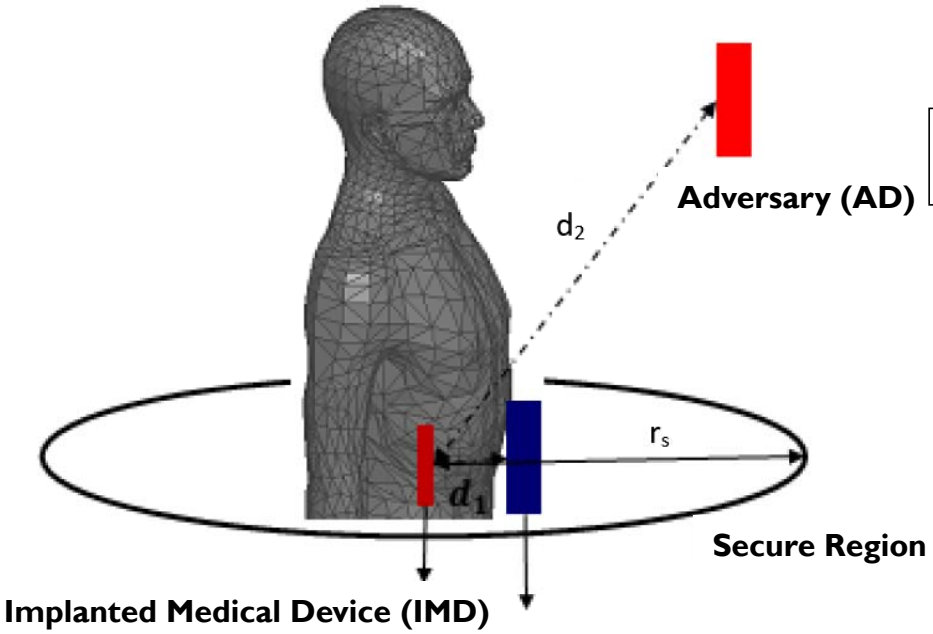


http://money.cnn.com/2017/05/16/technology/hospitals-vulnerable-wannacry-ransomware/
https://www.youtube.com/results?search_query=WiFi+jammer

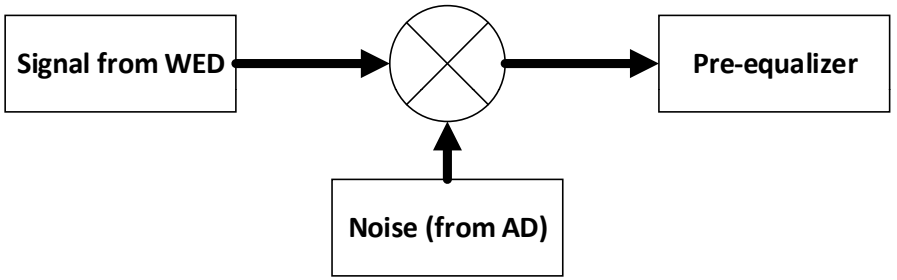
WBAN and Security



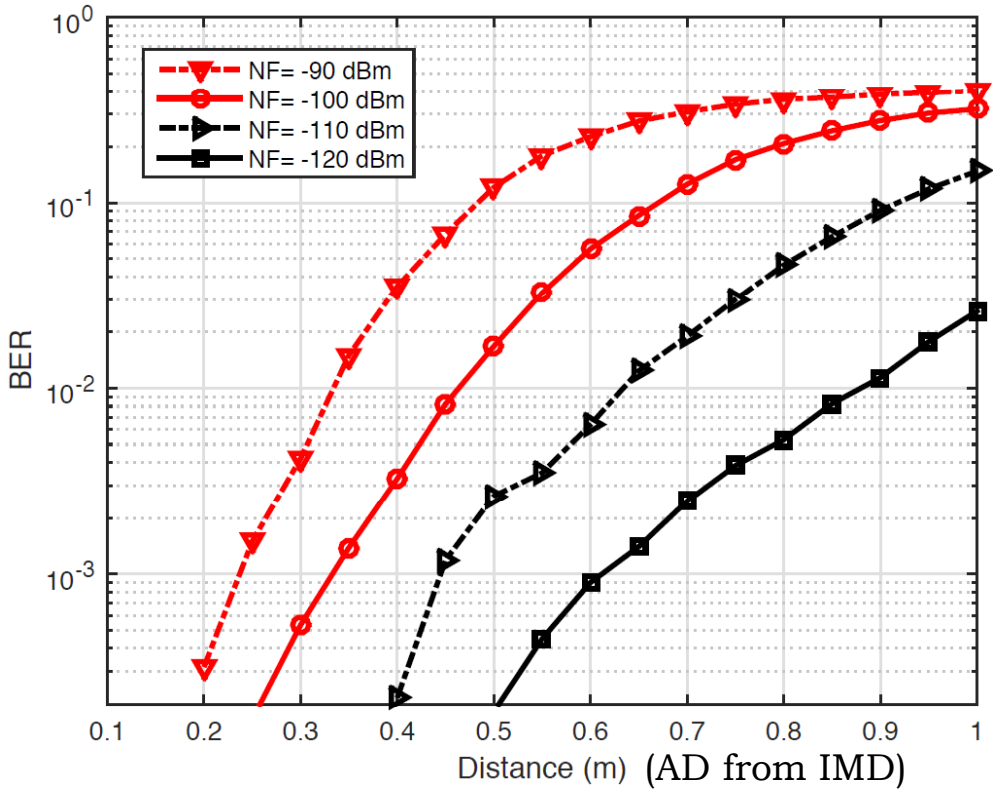
WBAN and Security



System setup [34]



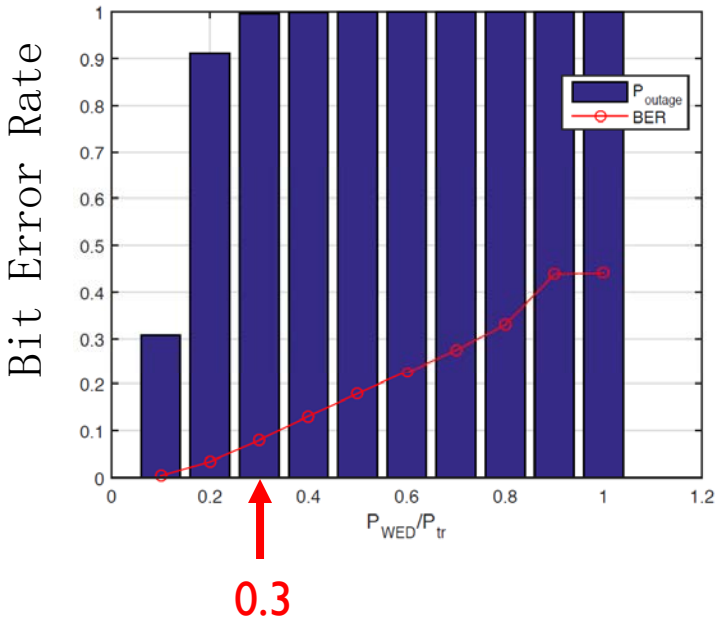
WBAN and Security



BER chart NFs [34]

WBAN and Security

AD(Adversary) to IMD (Implantable Medical Device) [34]



So, in this proposed method recommend P_{WED}/P_{tr} = 0.3

Conclusion

The IEEE WBAN standards were just approved 4-5 years ago, so **this is still a new area**

We are encouraged by the research in the areas of:

1) Energy management,
2) Interference avoidance, and
3) Security

But additional research is needed to allow mainstream success

All the research points to the inevitable success of WBAN technology to detecting life threatening emergencies *in advance*

Most importantly - just think of the impact that such technology could make based on U.S. statistics alone

800,000 strokes per year x 80% preventable = 640,000 people's lives changed

[1][2]

References

[1] National Stoke Association, "Reduce Your Risk of Stoke Starting Now," 2015. [Online]. Available: https://www.stroke.org/sites/default/files/resources/prevention-brochure-2015.pdf. [Accessed 12 April 2017].

[2] Samaneh Movassaghi, Mehran Abolhasan, Justin Lipman, David Smith, Abbas Jamalipour, "Wireless Body Area Networks: A Survey," *IEEE COMMUNICATIONS SURVEYS & TUTORIALS,* pp. 1658-1686, 2014.

[3] IEEE, "Part 15.6-2012: Wireless Body Area Networks," IEEE Standards Association, 2012.

[4] Mark A. Hanson, Harry C. Powell Jr., Adam T. Barth, "Body Area Sensor Networks: Challenges and Opportunities," *Computer,* vol. 42, pp. 58-65, 2009.

[5] IEEE, "P802.15.6/D04, Jun 2011 - IEEE Draft Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 15.6," IEEE Standards Association, 2011.

[6] IEEE, "Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) (Amendment 4)," IEEE Standards Association, 2013.

[7] Ali Hassan Sodhro, Ye Li, Madad Ali Shah, "Energy-efficient adaptive transmission power control for wireless body area networks," *IET Communications10.1,* pp. 81-90, 2016.

[8] Fabio Di Franco, Yu Ge, Ilenia Tinnirello, "On-body and off-body transmit power control in IEEE 802.15.6 scheduled access networks," *2014 IEEE 25th Annual International Symposium on Personal,* pp. 1254-1258, 2014.

[9] Chipcon, "SmartRF CC2420 2.4 GHz IEEE 802.15.4 / ZigBee-ready RF Transceiver," 9 June 2004. [Online]. Available: https://inst.eecs.berkeley.edu/~cs150/Documents/CC2420.pdf. [Accessed 22 April 2017].

[10] "ZIGBEE CC2420 wireless module," [Online]. Available: https://www.aliexpress.com/item/ZIGBEE-CC2420-wireless-module-So-the-best-best-antenna-on-sale-The-first-generation-of-classic/32687356651.html?spm=2114.40010208.4.6.d2SApt. [Accessed 22 April 2017].

[11] Abbas Arghavani, Haibo Zhang, Zhiyi Huang, "LPA: Learning-Based Power Aware Communication Protocol in WBANs," *2016 IEEE 14th Intl Conf on Dependable,* pp. 512-519, 2016.

References

[12] Mónica Vallejo, Joaquín. Recas, José L. Ayala, "Proactive and Reactive Transmission Power Control for Energy-Efficient On-Body Communications," *Sensors 15.3,* pp. 5914-5934, 2015.

[13] Shan Lin, Fei Miao, Jingbin Zhang, Gang Zhou, Lin Gu, Tian He, John A. Stankovic, Sang Son, George J. Pappas, "ATPC: Adaptive transmission power control for wireless sensor networks," *ACM Transactions on Sensor Networks (TOSN),* 2016.

[14] Sukhumarn Archasantisuk, Takahiro Aoyagi, Minseok Kim, Jun-ichi Takada, "Transmission power control in WBAN using the context-specific temporal correlation model," *2016 IEEE 27th Annual International Symposium on Personal, Indoo,* pp. 1-6, 2016.

[15] S.-L. Chen, "A Power-Efficient Adaptive Fuzzy Resolution Control System for Wireless Body Sensor Networks," *IEEE Access,* vol. 3, pp. 743-751, 2015.

[16] Mónica Vallejo, Joaquín. Recas, José L. Ayala, "An Accelerometer-Assisted Transmission Power Control Solution for Energy-Efficient Communications in WBAN," *IEEE Journal on Selected Areas in Communications,* vol. 34, pp. 3427-3437, 2016.

[17] Young Rok Jang, Yongok Kim, Jang-Won Lee, Daesik Hong, Sooyong Choi, "Adaptive Queue Management Scheme for Body Area Network with Energy Harvesting," BodyNets, 2013.

[18] Francesco Ivan Di Piazza, Stefano Mangione, Ilenia Tinnirello, "On the effects of transmit power control on the energy consumption of WiFi network cards," *International Conference on Heterogeneous Networking for Quality,* 2009.

[19] Huseyin Cotuk, Kemal Bicakci, Bulent Tavli, "The Impact of Transmission Power Control Strategies on Lifetime of Wireless Sensor Networks," *IEEE Transactions on Computers,* vol. 63, pp. 2866-2879, 2014.

[20] J.N. Laneman, D.N.C. Tse, G.W. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," *IEEE Transactions on Information Theory,* vol. 50, pp. 3062-3080, 2004.

[21] "Five Factors to Consider When Implementing a Wireless Sensor Network (WSN)," *National Instruments,* 2017.

[22] M. Maman, F. Mani, B. Denis, "Evaluation of multiple coexisting Body Area Networks based on realistic on-body and Body-to-Body channel models," *2016 10th International Symposium on Medical Information and Communication Technology (ISMICT),* pp. 1-15, 2016.

References

[23] Yena Kim, SeungSeob Lee, SuKyoung Lee, "Coexistence of ZigBee-Based WBAN and WiFi for Health Telemonitoring Systems," *IEEE Journal of Biomedical and Health Informatics,* vol. 20, pp. 222-230, 2016.

[24] Essafi Sarra, Tahar Ezzedine, "Performance improvement of the wireless body area network (WBAN) under interferences," *2016 IEEE 18th International Conference on e-Health Networking,* pp. 1-6, 2016.

[25] Bin Yuan, Jing Liu, Wenlong Liu, "DIM: A novel decentralized interference mitigation scheme in WBAN," *2015 International Conference on Wireless Communications & Signal Processing (WCSP),* pp. 1-5, 2015.

[26] Idrissa Abubakar, Jafri Din, Manhal Alhilali, Hong Yin Lam, "Interference and Electromagnetic Compatibility Challenges in 5G Wireless Network Deployments," *Indonesian Journal of Electrical Engineering and Computer Science,* pp. 612-621, 2017.

[27] Dong-Yeol Choi, Won-Kyung Kim, Jae-Hyun Kim, "Performance of analog and digital modulation schemes under sweep jamming," *2016 Eighth International Conference on Ubiquitous and Future Networks (ICUFN),* pp. 13-15, 2016.

[28] Jung-Hwan Hwang, Tae-Wook Kang, Jong-Hwa Kwon, "Effect of Electromagnetic Interference on Human Body Communication," *IEEE Transactions on Electromagnetic Compatibility,* vol. 59, pp. 48-57, 2017.

[29] O. T. Valle, G. Budke, C. Montez, "Experimental Assessment of Using Network Coding and Cooperative Diversity Techniques in IEEE 802.15.4 Wireless Sensor Networks," *2016 IEEE World Conference on Factory Communication Systems (WFCS),* pp. 1-4, 2016.

[30] Gaurav Somani, Manoj Singh Gaurb, Dheeraj Sanghic, Mauro Contid, "DDoS attacks in cloud computing: Collateral damage to non-targets," *Computer Networks,* vol. 109, pp. 157-171, 2016.

[31] Shyamnath Gollakota, Haitham Hassanieh, Benjamin Ransford, Dina Katabi, Kevin Fu, "They can hear your heartbeats: non-invasive security for implantable medical devices," *ACM SIGCOMM Computer Communication Review,* vol. 41, no. 4, pp. 2-13, 2011.

[32] Kanchan Kaushal, Varsha Sahni, "Early Detection of DDoS Attack in WSN," *International Journal of Computer Applications,* vol. 134, pp. 14-18, 2016.

References

[33] A.J. BURNS, M. ERIC JOHNSON, AND PETER HONEYMAN, "A brief chronology of medical device security," *Communications of the ACM,* vol. 59, pp. 66-72, 2016.

[34] Z. Esat Ankaralı, Marwa Qaraqe, "Physical layer security for wireless implantable medical devices," *2015 IEEE 20th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD),* pp. 144-147, 2015.

[35] Caixia Xie, Liang Xiao, "User-centric view of smart attacks in wireless networks," *2016 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB),* pp. 1-6, 2016.

[36] A. Fatih Demir, Qammer H. Abbasi, Z. Esad Ankaralı, "Numerical characterization of in vivo wireless communication channels," *2014 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications,* pp. 1-3, 2014.

[37] Jay Shree Ranjit, Seokjoo Shin, "A Modified IEEE 802.15.4 Superframe Structure for Guaranteed Emergency Handling in Wireless Body Area Network," *Network Protocols and Algorithms 5.2,* pp. 1-15, 2013.

[38] Miftadi Sudjai, Le Chung Tran, Farzad Safaei, Tadeusz Wysocki, Son Lam Phung, "High-speed adaptive wireless body area networks," *EURASIP Journal on Wireless Communications and Networking,* 2016.

[39] W. Shen, "Secure In-Band Bootstrapping for Wireless Personal Area Networks," *in IEEE Internet of Things Journal,* vol. 3, pp. 1385-1394, 2016.

[40] Marwa Salayma, Ahmed Al-Dubai, Imed Romdhani, Youssef Nasser, "Wireless Body Area Network (WBAN): A Survey on Reliability, Fault Tolerance, and Technologies Coexistence," *ACM Computing Surveys (CSUR),* vol. 50, no. 1, April 2017, 2017.

[41] Z. Esat Ankaralı, Z. Esat Ankaralı, Marwa Qaraqe, "Physical layer security for wireless implantable medical devices," *2015 IEEE 20th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD),* pp. 144-147, 2015.

[42] A. Fatih Demir, Qammer H. Abbasi, Z. Esad Ankarali, "Numerical characterization of in vivo wireless communication channels," *2014 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications,* pp. 1-3, 2014.

Questions?