Utilizing Energy Efficiency and QoS awareness for Receiver-Arbitrated and Sender-Predicted MAC Protocol in Wireless Sensor Network

Huan Yang¹, Lingyan Bao², Jia Luo², Biao Deng², Hui Wang*²

¹School of Information, BaoShan University, Baoshan, Yunnan, 678000, China
²School of Software, Yunnan University, Kunming, Yunnan, 650091, China

*Corresponding author’s e-mail: billyanghuan@163.com

Abstract. In this paper, we exploit energy-efficiency and QoS-awareness for receiver-arbitrated and sender-predicted MAC Protocol (EQAP-MAC) in wireless sensor network. EQAP-MAC improves the transmission concurrency by separating control stream from data stream; minimizes energy consumption by sender by predicting receiver’s wake-up time; supports priority-based QoS through priority-based data flow selected, arbitrated and interrupted mechanisms; reduces transmission interference between the nodes by interleaving neighbor nodes’ wake-up time; improves system throughput and reduces the data stream transmitting delay by pipelining mechanism and optimizing send sequence. We have implemented EQAP-MAC on TinyOS and evaluated its performance on testbed. The result shows EQAP-MAC achieves higher concurrent performance and priority-based QoS guarantee with lower energy consumption compared with RI-MAC and X-AMC.

1. INTRODUCTION

With the development of economy and technology, wireless sensor network has been applied in some new areas, such as factory automation [1], [2], health monitoring [3], multimedia surveillance [4], [5] and smart city [6]. In these new applications, wireless sensor networks [7], [8], [9], [10], [11], [12], [13], [14] have been expected to handle multiple data streams, which have different requirements for QoS. For example, in factory automation control, if some key data streams are delayed, it may lead to serious consequences. Therefore, a stable wireless sensor network, which can guarantee real-time for the critical data streams and provides mechanism for QoS has been widely studied in the literature [15].

In the literature, Synchronous MAC (S-MAC) [16], [17] adopted Network Allocation Vector (NAV), CSMA and RTS/CTS mechanism to evade conflict and prevent from eavesdropping, however, there are some important issues which have not been addressed, such as idle listening and transmission delays [16]. B-MAC was investigated in [18], [19], which adopted Low Power Listening technique to reduce energy consumption, yielding better packet deliver rate, energy consumption, throughput and latency than S-MAC. However, it has to send the long preamble each time before date transmission and the neighbor node which is not the target suffers from overhearing. Wise MAC studied in [20] proposed to learn the receiver’s sampling scheme to minimize the preamble size. Sender node sent a longer preamble once B-MAC sent at the first time. When Receiver node received this preamble, it sent back an ACK not only inform the sender that the preamble is received but also piggyback the next wake up time. Thus the send record this information in the neighbor table. When the sender want to
send date to this receive next time, it looks up the information in the neighbor table and calculate the right time to send a minimized preamble just before the receiver wakes up. X-MAC [21], [22] separate the preamble for the serials of short preamble with target address embedded. If the receiver is not the target, it immediately return to sleep, thus the overhearing is reduced a lot. If the receiver is the target and wake up, it sends back an early ACK after received the short preamble, then the sender knows the target node is awake and stops sending preamble and starts data transmission. X-MAC results better energy efficiency and short data transmission delay, but the preamble still dominates the energy consumption. RI-MAC [23], [24] applied the idea of receiver initiated transmission to duty-cycle MAC protocols to achieve high concurrent performance while still maintain low energy consumption [23]. Node periodically wakes up and broadcasts beacon to notify the neighbor who is awake, if the sender wants to send a data, it should wait for receiver’s beacon, after gets the beacon it starts transmission. However, the disadvantage of RI-MAC is idle-listening problem and can not keep higher performance which we have solved in EQAP-MAC. RW-MAC [25], [26] is on the basis of RI-MAC and combined some mechanism of Wise-MAC to avoid unnecessary idle listening. It is a receiver-initiated MAC which reduces energy consumption by precisely predicting the receiver’s wakeup time and at the same times achieves high concurrent performance. In addition RW-MAC also introduces optimized data frame transmission sequence mechanism to improve throughput and concurrency.

In order to meet new demands for wireless sensor network application, a new MAC protocol called EQAP-MAC (Energy- Efficient QoS-aware and Receiver-Arbitrated Sender-Predicted MAC [27] Protocol for WSN) has been designed, which has following features:

- In order to improve the transmission concurrency, the data frame and control frame are transmitted in different channel. The whole network uses the same channel for control frame, and senor nodes use different channel to receive data.
- Sensor nodes periodically wake-up and sleep in asynchronous way to save energy.
- Sender estimates receiver’s wake-up time to decrease listening time and reduce energy consumption.
- In order to increase the throughput and decrease the average hop delay, packets are transmitted in pipeline with the optimized transmitting order.
- Packets with the highest priority can be transmitted once the receiver has been woken up by given selecting mechanism of data to provide QoS.
- Through Request-to-Send,arbitration,Arbitrate-to-Send,arbitration feedback, frames transmitting and ACK, the transmitting collision can be avoided and packets with higher priority can be processed and transmitted earlier.
- Avoid two neighboring nodes wake up at the same time by interleaving their wake-up time. So the collision between the neighboring nodes is avoided.

The rest of the paper is organized as follows. In Section 2, we describe the principle of EQAP-MAC. In Section 3, we describe how EQAP-MAC provides QoS transmission. Our conclusions are presented in Section 4.

2. EQAP-MAC DESIGN

EQAP-MAC is an improvement of RW-MAC[9], the basic operation are the same as RW-MAC, include calculating sleep wait time, interleaving node wake-up time and sender preestimated recipient wake-up time etc, but the ideas of receive date stream arbitration mechanism, data flow interruption mechanism and priority based QoS data stream transmission mechanism are the new. EQAP-MAC achieves higher concurrent performance which inherited from RI-MAC, it combines the strengths of RI-MAC and Wise-MAC while resolve their weakness to achieve higher performance and low energy consumption. The design of EQAP-MAC and its improvements are described in detail in the following text.
2.1 Energy Efficient
In order to support multiple data streams and reduce channel contention, EQAP-MAC adopts multi-channel mechanism. The data frame and control frame are transmitting in different channel, the whole network use one channel transmit control message and other channel for sensor nodes shared to receive data. In this way data flows concurrency can be improved and the energy efficiency improved too. Like RW-MAC, we also use interleaving node wake-up time and pre-estimating recipient wake-up time in EQAP design. However, EQAP-MAC uses asynchronous periodic listen and sleep to reduce energy consumption. EQAP-MAC uses RTS /ATS/DATAs/ACKs mechanisms for data transmission. In RTS listening period, node listens RTS frame which sended from its neighbors. In ATS sending period, node arbitrates the received RTS frame, selects the RTS sender with highest priority and sends it ATS frame. After arbitration period, sensor node selected starts to transmitting data and other nodes shut down their RF module to sleep. Moreover, RTS/ATS can piggyback nodes wake-up interval. Neighboring nodes advertise themselves established wake-up time through exchanging RTS/ATS frame, so node can calculate the neighboring nodes’ next wake-up time based on these information.

2.2 Priority based QoS Data Stream Transmission
In order to guarantee high priority data stream processed and transmitted earlier, we have designed Transmission Data Stream Selection, Receive Data Stream Arbitration and Data Flow Interruption Mechanisms. The RTS frame sender sent contains not only receiver’s destination address but also sender flow’s priority and estimated transmission time. Similarly, the ATS frame send by receiver contains arbitration priority, sender address and estimated transmission time.

The sender and receiver adopt CSMA/CA based channel access mechanism to compete for channel when they sending RTS/ATS frame. But when sending data, they can send directly instead of using CSMA/CA. Because data streams and control frame are transmitted in different channels, there does not exist collision between data stream and RTS/ATS frame, and different data streams cannot interfere with each other. In order to make all the neighbors received RTS/ATS frame, IEEE 802.15.4 hardware address filtering should be shut down. During data transmission period, sender must retransmit data frame if no ACK received and receiver must acknowledge every time when receiving data frame. If receiver waiting for a period of time, no new data frame arrived, which means sender may be abnormal, receiver must immediately shut down RF module and sleep. When data stream transmission is over, sender and receiver immediately switch to control channel and continue to listen. If no new control frame arrived, they close RF module and sleep.

![Fig1.Optimizing data frame transmission order.](image)
3. PRIORITY BASED QOS TRANSMISSION

3.1 Transmission Data Stream Selection

In wireless sensor networks, data collected is generally busy and discontinuous. For example, when event occurs, a large number of data may be collected and sent by WSNs. In many applications, we think that there exist several concurrent services and different services transmit data streams with different priorities. In QoS guarantee model based on priority, how to ensure that firstly select and transmit the data flow with high priority is the key to guarantee QoS. However, EQAP-MAC can select and transmit data streams in order of their precedence, not affecting network performance.

3.1.1 Transmit data stream in pipeline and optimize data frame transmission order: EQAP-MAC adopts mechanisms of the pipeline data packet transmission and sending order optimizing. Upper layer service transmits data streams to the MAC layer in pipeline concurrently. MAC layer accepts all the transmission request of data stream from upper layer service, and estimate given wake-up time of data flow receiver. Then, according to order of the wake-up time of the receivers, it selects the first wake-up receiver and sends out data flow. As shown in Figure 2, sender S, after accepting sending request data stream from upper layer service at t2 and t3, transmit data stream to receiver Rj at t4, and then, transmit data stream to receiver Ri at t5.

3.1.2 Data streams queue model based on priority and neighbors wake-up time: Since data streams are likely to be produced at any time and each receiver’s wake-up time is uncertain; so the best data stream selection strategy should be ensure that the high-priority data stream to be sent out in the most appropriate time. That means, when the receiver of the high-priority data stream wake up, we should start to process and transmit high-priority data stream even the low-priority data stream is been sending. We interrupt the transmission of low priority data stream and begin to deal with the request of the high-priority data stream as shown in Figure 2.

In order to allow the sender to estimate receivers wake-up time, EQAP-MAC records the neighboring nodes reference wake-up time and other information in neighbor table (NeighborQueue), caches data stream pointer in data stream queue (MessageQueue), and maps each element in the data flow queue to element of neighbor table by neighbor information map (NeighborMsgMap) tables. Multiple concurrent services send data flow to lower layer in pipeline according to their own needs.
Lower layer caches data stream pointer in data stream queue, and creates a mapping bits according to data stream destination address in neighbor information mapping table. Whenever the neighbor in the neighbor table reaches recorded wake-up time, sender should start data stream sending selection process. In selection, it is only to find the present wake neighbor entries in the neighbor information mapping table, and chooses the highest priority data stream, then starts processing and transmitting. If there exist two data streams with the same priority, these two data streams should be combined into one data stream to inform the system for processing and transmitting because the tow data streams have the same destination address.

3.2 Receive Data Stream Arbitration
During the RTS listening period, receiver listens the RTS frames sent by transmitters. During the ATS transmitting period, receiver arbitrates the data flows carried in the RTS frame, selects the data flow with highest priority, and broadcasts ATS which contains the arbitrating results. Then the arbitrating feed-back period comes. If transmitters have disputes about the arbitrating results, they will send their RTS to the arbitrator. If the priority of RTS frames received by the arbitrator is higher than the original arbitrating result, then arbitrator will arbitrate and select again. Until no nodes have disputes about the arbitrating result, the receiver switches channel and waits for data transmitting. Since RTS/ATS frames contain estimated data transferring time and receivers have residing period after the end of data transmitting. Nodes can open RF module and send RTS again according to the present transmitting time and receiver’s residing period, if it is not get the allowance for sending its data stream. In this way sender can send data stream as quickly as possible, then the latency is reduced and network throughput are improved.

In order to let the low priority data sender sleep as early as possible, when a receiver receives other sender’s RTS frame and judges its own data priority is not the highest and second, it can straightly turn into sleep and do not wait for receiver’s arbitration results. If a sender received receiver’s ATS frame and found the priority in arbitration result is lower than its own priority, it can send RTS again and notified receiver the arbitration result is improper. If the sender judges his data priority is the highest or the second, he must wait until the arbitration period ends, and decides whether or not continue to listen the channel.

3.3 Data flow interruption
Because data frame and control frame transmitted in different channel, when sender S are transmitting data stream to receiver R, it will not affect other neighbor’s control stream and data stream transmitting. However, the current data transmitting will affect higher priority data streams transmitting if S or R involved in it. In the following situation, we should interrupt current data streaming transmitting to provide QoS: 1) sender S sends higher priority data streams to other neighbor; 2) receiver R sends higher priority data streams to other neighbor; 3) receiver R or sender S have reached its established wake-up time. EQAP-MAC uses interrupt frame (INT) to let the high priority data stream interrupt the lower priority data streams transmission.

3.3.1 Sender S Send Higher Priority Data Streams To Other Neighbors: As shown in figure 3, sender S is transmitting a data stream with priority 2 to receiver $R_j$. At the moment $t_0$, upper layer of S want to send data stream with priority 1 to $R_i$. 
Fig 3. S-not-R Interrupt mechanism: compete success.

S pre-estimated that receiver R_i will wake up at t_2, so S immediately send INT fame to R_j after transmitting data frame at t_1 which is earlier than t_2. INT indicates a data stream with priority 1 which destination is R_i interrupted current data transmission. After R_j received the INT frame, it feedback a INT(1) frame. After received the feedback INT(1), S records the sequence number of current successfully transmitted frame. Then S and R_j switch the channel to fixed control channel CFixed. S requests to send data stream with priority 1 to R_i at t_2. If S win the arbitration after R_i listening period and arbitration feedback period, S switches the channel to reception channel which is same to R_i and start transmission data stream with priority 1 to R_i. R_j knows S won the arbitration at t_3, then R_j turn into sleep. At t_4, after data stream with priority 1 transmission between S and R_i is over, they all switched the channel to fixed control channel CFixed and entered residing period. If there is no frame arrived in residing period, both of them turn into sleep. By pre-estimating, S knows R_j will wake up at t_6 moment, then S opens RF module at that moment and send request R_j. When R_j wakes up, new arbitration period will be started.

3.3.2 Receiver R Send Higher Priority Data Streams To Other Neighbors: The interrupt processing when receiver R sends higher priority data flow to other neighbor is similar to above. But if receiver has higher data flows than received frame, it sends interrupt frame INT to sender instead of ACK, informing sender need to interrupt current data stream transmitting. When sender R waiting for ACK response, it have received INT frame which priority is higher than current data stream. R knows the receiver has higher priority data stream to send, then S turn into the interrupt processing.

3.3.3 Receiver R Or Sender S reached Its Established Wake-Up Time: The processes of receiver or sender reaches its establish wake-up time is similar. Here we discuss the receiver R reached its established wake-up time.

In Figure 4, sender S_j are transmitting s data stream with priority 2, and receiver R knows he will reach his own established wake-up period at t_2. Then receiver sends interrupt frame INT to S_j instead of send feedback after receiving data at t_1. S_j feedbacks an interrupt frame to receiver R after receiving interrupt frame, and records current data streaming process. At t_2, S_j and other senders send RTS frame to R for competing data stream transmission. If S_j won, it continues to send the data stream interrupted. Otherwise, S_j must wait for transmission completed.
4. EXPERIMENT AND EVALUATION

In our experiments, we use a testbed called NPUmote [28] which is similar to IRIS platform to run benchmark. The MCU of NPUmote is Atmega1281 which has 8K SRAM, 4K EEPROM and 128K FLASH.

We use 6 NPUmote nodes, three of them as the sender, the other three as the receiver. The radio signal of each node can cover other five nodes. Each sender has three different priority services, every service transmit data stream to different receiver. Each service has 25 data frames buffer and the payload of data frame is 28 bytes. so transmit each data frame need approximately 1500us.

We have compared the performance of EQAP-MAC with RW-MAC, RI-MAC and X-MAC. Figure 5 shows the experiment results. From Figure 5(a) and (b), we can see EQAP-MAC and RW-MAC can significantly reduce sender’s energy consumption, this is because they all adopt pre-estimated receiver’s wake up time. So they guarantee sender open wireless RF module before receiver wake up and start transmitting data. From Figure 5(c), we can see the transmission delivery rate of EQAP-MAC protocol is higher than other three protocols. The advantage is more obvious with the busty data increasing. Comparing (c) with (a)(b), we can conclude that EQAP-MAC protocol’s network throughput and transmission concurrency is higher than other three MAC protocols. Because EQAP-MAC uses multi-channel, control flow and data flow separation and each node receiving data in different channel, network throughput and transmission concurrency is increased.
Figure 5(d) shows the service transmission delivery rate on three nodes when the transmission time interval is 128 ms. The 1, 5, 9 priority services on node 4 send data to node 32, 9, and 22 separately. The 3, 6, 8 priority services on node 32 send data to node 32, 9, and 22 separately and the priority service 2, 4, 7 on node 13 send data to 32, 9, and 22. Since the node 32 receives the 1, 2, 3 priority data streams, node 9 receives 7, 8, 9 priority data streams. Each node’s wake up time are interleaved and data stream receiving channels are different, thus the priority of 3, 6, and 9 service delivery rate are below than other two high-priority services on the same node. EQAP-MAC is designed to ensure that the data stream of high-priority services is preferentially processed and transmitted. The phenomenon of 5(d) due to different receivers have different wake up time. Receiver must guarantee high priority data flow are firstly processed and transmitted. Different receivers must transmit data streams parallelly. In this way, systems throughput is improved and transmission delay decreased.

5. CONCLUSION AND FUTURE WORK

In this paper, we developed an energy-efficient and QoS based high performance MAC protocol called EQAP-MAC for wireless sensor network. The result of the experiments shows that EQAP-MAC has advantages in energy efficiency, network throughput and transmission delay.

This paper has not discussed how to guarantee real-time requirements. Therefore, we will consider how to guarantee real-time performance at the MAC layer in our future research, because there are many applications in Wireless Sensor Network need to have real-time performance.
ACKNOWLEDGEMENT

The works of H. Yang have been supported in part by National Science and Technology Major Project of China under grant No.2012ZX03005007, in part by NPU Foundation for Fundamental Research under grant NPU-FFR-JC20100218, in part by Baoshan Science and technology project under grant 2019kj17, in part by the Joint Youth Project of Universities and Colleges in Yunnan Provincial Science and Technology Department, 2017FH001-104. The works of L. Bao, J. Luo and B. Deng have been supported in part by the National Natural Science Foundation of China under Grant 61801418, in part by Yunnan Applied Basic Research Projects under Grant 2019FD-129, and in part by the Open Foundation of Key Laboratory in Software Engineering of Yunnan Province under Grant 2017SE203.

REFERENCES

[1] K. Islam, W. Shen, and X. Wang, “Wireless sensor network reliability and security in factory automation: A survey,” IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), vol. 42, no. 6, pp. 1243–1256, 2012.

[2] Q. F. Shang and L. Zhang, “Automation control system of pharmaceutical factory based on wireless sensor network,” in Applied Mechanics and Materials, vol. 397. Trans Tech Publ, 2013, pp. 1271–1277.

[3] T. Kawamura, S. Ryuo, and N. Iwasawa, “Power consumption prediction method for train-health monitoring wireless sensor networks,” Electronics and Communications in Japan, vol. 101, no. 6, pp. 24–32, 2018.

[4] R. Bhatt, A. Arvind, and P. Bhatt, “An integration framework of three-dimensional wireless multimedia sensor network with cloud computing for surveillance applications,” 2016.

[5] Y. Pan, S. Li, X. Zhang, J. Liu, Z. Huang, and T. Zhu, “Directional monitoring of multiple moving targets by multiple unmanned aerial vehicles,” in GLOBECOM 2017-2017 IEEE Global Communications Conference. IEEE, 2017, pp. 1–6.

[6] C. Wang, S. Li, Y. Pan, and B. Li, “An application-driven heterogeneous internet of things integration architecture,” in International Conference on Intelligent Networking and Collaborative Systems. Springer, 2019, pp. 586–596.

[7] H. Shen and G. Bai, “Routing in wireless multimedia sensor networks: A survey and challenges ahead,” Journal of Network and Computer Applications, vol. 71, pp. 30–49, 2016.

[8] C. C. Gami and K. J. Sarvakar, “Wireless sensor network: A survey,” in International Journal of Research in Information Technology, 2013, pp. 173–198.

[9] X. Xia, S. Li, Y. Zhang, T. Gu, and Y. Pan, “Towards energy-balanced data transmission for lifetime optimization in wireless sensor networks,” in 2016 IEEE International Conference on Communications (ICC). IEEE, 2016, pp. 1–7.

[10] J. Liu, S. Wang, S. Li, X. Cui, Y. Pan, and T. Zhu, “Mcts: Multi-channel transmission simultaneously using non-feedback fountain code,” IEEE Access, vol. 6, pp. 58 373–58 382, 2018.

[11] W. Wang, X. Liu, Y. Yao, Y. Pan, Z. Chi, and T. Zhu, “Crf: Coexistent routing and flooding using wifi packets in heterogeneous iot networks,” in IEEE INFOCOM 2019-IEEE Conference on Computer Communications. IEEE, 2019, pp. 19–27.

[12] J. Yu, H. Wang, M. Zhao, W. Li, H. Bao, L. Yin, and M. Wu, “Energy minimization for mobile edge computing networks with time-sensitive constraints,” 2020.

[13] M. Zhao, J. Y. Ryu, J. Lee, T. Q. Quek, and S. Feng, “Exploiting Trust Degree for Multiple-Antenna User Cooperation,” IEEE Trans. Wireless Commun., vol. 16, no. 8, pp. 4908–4923, 2017.

[14] J. Yu, M. Zhao, W. Li, D. Liu, S. Yao, and W. Feng, “Joint offloading and resource allocation for time-sensitive multi-access edge computing network,” in Proc. IEEE WCNC, 2020, pp. 1–6.

[15] M. A. Yigitel, O. D. Incel, and C. Ersoy, “Qos-aware mac protocols for wireless sensor networks:
A survey,” Computer Networks, vol. 55, no. 8, pp. 1982–2004, 2011.

[16] O. Yang and W. Heinzelman, “Modeling and performance analysis for duty-cycled mac protocols with applications to s-mac and x-mac,” IEEE Transactions on Mobile Computing, vol. 11, no. 6, pp. 905–921, 2012.

[17] Y. L. H. B. C. Huajun, “An analysis of s-mac protocol for wireless sensor networks,” Technology Wind, vol. 2011, no. 14, p. 21, 2011.

[18] V. K. Sachan, S. A. Imam, and M. Beg, “Energy-efficient communication methods in wireless sensor networks: A critical review,” International Journal of Computer Applications, vol. 39, no. 17, pp. 35–48, 2012.

[19] D. Ghose, F. Y. Li, and V. Pla, “Mac protocols for wake-up radio: principles, modeling and performance analysis,” IEEE Transactions on Industrial Informatics, vol. 14, no. 5, pp. 2294–2306, 2018.

[20] F. D. Miyandoab, J. C. Ferreira, and V. M. G. Tavares, “Analysis and evaluation of an energy-efficient routing protocol for wsns combining source routing and minimum cost forwarding,” Journal of Mobile Multimedia, vol. 14, no. 4, pp. 469–504, 2018.

[21] M. Xia, Y. Dong, and D. Lu, “W-mac: A workload-aware mac protocol for heterogeneous convergecast in wireless sensor networks,” Sensors, vol. 11, no. 3, pp. 2505–2524, 2011.

[22] Z. Lu, T. Luo, and X. Wang, “Xy-mac: a short preamble mac with sharpened pauses for wireless sensor networks,” in 2012 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2012, pp. 1550–1554.

[23] S. Henna, “Sa-ri-mac: sender-assisted receiver-initiated asynchronous duty cycle mac protocol for dynamic traffic loads in wireless sensor networks,” in International Conference on Mobile Lightweight Wireless Systems. Springer, 2011, pp. 120–135.

[24] Y. Sun, O. Gurewitz, and D. B. Johnson, “Ri-mac: a receiver-initiated asynchronous duty cycle mac protocol for dynamic traffic loads in wireless sensor networks,” in Proceedings of the 6th ACM conference on Embedded network sensor systems, 2008, pp. 1–14.

[25] D. Yang, Y. Qiu, S. Li, and Z. Li, “Rw-mac: An asynchronous receiver-initiated ultra low power mac protocol for wireless sensor networks,” 2010.

[26] Y. Qiu, S. Li, D. Yang, and Z. Li, “Rwb: An efficient receiver-initiated single-hop broadcast protocol for asynchronous mac in wireless sensor networks,” in Recent Advances in Computer Science and Information Engineering. Springer, 2012, pp. 261–266.

[27] S. Henna and B. Saleeemi, “Sender assisted receiver initiated mac with predictive-wakeup for wireless sensor networks,” in Proceedings of the Mediterranean Conference on Information & Communication Technologies 2015. Springer, 2016, pp. 599–605.

[28] Y. Qiu, S. Li, W. Wu, and Z. Li, “General mote platform design for wireless sensor network,” Computer Engineering and Applications, vol. 48, no. 23, pp. 90–94, 2012.