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# Advanced Approaches for Wireless Sensor Network Applications and Cloud Analytics

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***Abstract*—Although wireless sensor network applications are still at early stages of development in the industry, it is obvious that it will pervasively come true and billions of embedded microcomputers will become online for the purpose of remote sensing, actuation and sharing information. According to the estimations, there will be 50 billion connected *sensors* or *things* by the year 2020. As we are developing first to market wireless sensor-actuator network devices, we have chance to identify design parameters, define technical infrastructure and make an effort to meet scalable system requirements. In this manner, required research and development activities must involve several research directions such as massive scaling, creating information and big data, robustness, security, privacy and human-in-the-loop. In this study, wireless sensor networks and Internet of things concepts are not only investigated theoretically but also the proposed system is designed and implemented end-to-end. Low rate wireless personal area network sensor nodes with random network coding capability are used for remote sensing and actuation. Low throughput embedded IP gateway node is developed utilizing both random network coding at low rate wireless personal area network side and low overhead websocket protocol for cloud communications side. Service-oriented design pattern is proposed for wireless sensor network cloud data analytics.**

## I. Introduction

It gradually becomes clear that wireless sensor network applications and Internet of things concept will reshape our environment, facilities, cities and our world in the upcoming decades [1]. With the help of new developments in wireless sensor networks (WSN) and Internet of things (IoT), novel application fields and scenarios will be formed according to the needs of human acitivities. There will be an explosion in the number of cloud services which are related to the usage of big data collected from WSN nodes. At this stage, several threats emerge for the scalability, manageability and efficiency of the overall system as the number of devices increase [2]. To ensure effective manageability and scalability, efficient design attitude should start from the most simplest unit to the most complex one in WSN system infrastructure. The efficiency in radio frequency (RF) transmission is not only about physical layer (PHY) but also all of the protocol layers over PHY. Network coding is a promising technique for using radio spectrum efficiently. If we can converge both network coding techniques in low rate wireless personal area networks (LR-WPAN) and service-oriented design in cloud analytics, we can achieve more efficient WSN ecosystem.

## II. Background

### A. Service-Oriented Architecture

Service-oriented design pattern originally evolved from the object-oriented analysis and design concepts [3][4]. In object-oriented analysis, the system functionality is isolated from the implementation constraints. Certain characteristics of each object can be abstracted according to the requirements and overall system can be managed more simply. Once the object paradigm is defined, inheritance-based design performs well to some extent, while component-based design pattern helps us to define objects in a more complex compositions. Service-oriented architecture comes up right here by defining a component which provides a black-box encapsulation of related services. This provides distribution of system funtionality and simplification of complex problems within each system.

### B. Network Coding

The idea of network coding was first introduced at the beginning of 2000s, now there are lots of studies and implementations [5][6][7]. Let's begin with the famous example to summarize the idea behind network coding. In the scenario shown in Figure 1, Alice and Bob wants to exchange packets via a relay node in between. First, Alice sends her packet to relay node and then relay node forwards it to Bob. Thirdly, Bob sends his packet to relay node and fourth relay node forwards it to Alice. This data exchange method requires 4 cycles. Let's examine the scenario with network coding approach. First Alice sends her packet to relay node and second Bob sends his packet to relay node. In the third step, relay node exclusive ORs (XOR) the two packets and transmits the XORed version. Since Alice and Bob know their own packets, they simply XOR the received packet with their own packets and they obtain each other's packet. The packet exchange ends with 3 cycles and saved cycles can be used for new packet transmissions which increases throughput.


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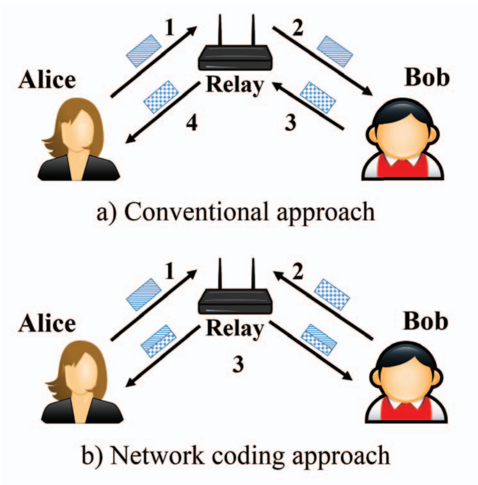


Fig. 1. Conventional (a) vs. network coding (b) approach. 3 transmissions instead of 4 saves 1 transmission cycle for any other data exchange.

Network coding is a promising method for future wireless networks and it has lots of advantages. Some of the most important IoT related advantages of network coding are low complexity for near-optimal routing [7][8][9][10], throughput enhancement [5], robustness to link failures and packet losses [8] [11].

### *C. WebSocket Protocol*

Historically, web applications which needs bidirectional communication between client and server has used inefficient polling techniques for updates from server while sending upstream messages as a distinct hyper-text transfer protocol (HTTP) calls. This caused forcing the server to open more than one transmission control protocol (TCP) sockets for each client, high overhead messages for each client-to-server HTTP calls and keeping the mapping from each outgoing connections to the incoming connection to track replies. A simpler solution could be to use single TCP connection for full-duplex communication between client and server. This is the underlying idea of WebSocket protocol. The WebSocket protocol is designed to overcome technical insufficiencies of existing HTTP based bidirectional communication technologies while exploiting existing infrastructure such as proxies, filtering and authentication. It works over HTTP ports 80 and 443 to support HTTP proxies and intermediaries. The protocol has two main states called handshake and the data transfer. As an example, the handshake message from client to server looks as follows:

*GET /chat HTTP/1.1*
*Host: server.example.com*
*Upgrade: websocket*
*Connection: Upgrade*
*Sec-WebSocket-Key: dGhlIHNhbXBsZSBub25jZQ==*
*Origin: http://example.com*
*Sec-WebSocket-Protocol: chat, superchat*
*Sec-WebSocket-Version: 13*

Once the handshake between client and server successfully ended, a two-way communication channel is established over one TCP connection and the data transfer part starts. Now each side can send data frames at will without waiting the other party. As the last detail for a brief introduction to WebSocket protocol, there are some specific frames *ping* and *pong*, used between client and server to keep TCP connection alive by preventing intermediary network devices closing the connection because of timeouts.

## III. System Realization

### *A. LR-WPAN Embedded IP Gateway*

WSN applications generally exploit from low throughput LR-WPAN protocols. One of the most widespread protocols that uses IEEE 802.15.4 LR-WPAN is ZigBee. Mesh network capability, low-power consumption and open source availability makes ZigBee preferable to other technologies. However, ZigBee protocol, as other LR-WPAN protocols, needs a gateway device to be able to communicate with the devices in IP domain. Thanks to the low cost high performance embedded microcontrollers, implementing embedded IP gateway for a ZigBee network becomes an attainable solution. As one alternative of quiet a lot solutions, we preferred Broadcom's brand-new wireless Internet connectivity for embedded devices (WICED) platform in combination with TI's CC2530 ZigBee network processor (ZNP) to realize LR-WPAN embedded IP gateway. In this combination, CC2530 has a low power 8051 core while WICED module has ARM Cortex-M3 microprocessor. Since, 8051 core in CC2530 with limited processing power, RAM and ROM size won't be suitable for being the main processor of gateway node, ARM Cortex-M3 core in WICED system in package (SiP) is chosen as the central processor.

WICED platform comes with two alternatives for IP stack and real time operating system (RTOS): NetX or LwIP TCP/IP stacks and ThreadX or FreeRTOS embedded operating systems. In our application, ARM Cortex-M3 reduced instruction set computing (RISC) microprocessor using ThreadX or FreeRTOS @120MHz on WICED is more suitable for handling IP network interfacing and forwarding tasks of the gateway node, while ZNP (ZigBee Network Processor) is in charge of interfacing ZigBee network. Proposed system architecture can be seen in Figure 2. At the right hand side, ZNP system architecure is shown. It uses IEEE 802.15.4 PHY and medium access control (MAC) layers under ZigBee network and application layers. ZNP has a serial peripheral interface (SPI) to communicate with the host processor. At the left hand side, WICED system is shown. WICED features IEEE 802.11n PHY and MAC layers under transport and network layers. Over the transport layer, WebSocket protocol operates as one of the low overhead, full-duplex communication protocols over a single TCP connection.

When we think about two wireless technologies at the same node, we have to consider coexistence analysis. IEEE 802.15.4 Sub-1 GHz ZigBee modules combined with a 2.4 GHz or 5

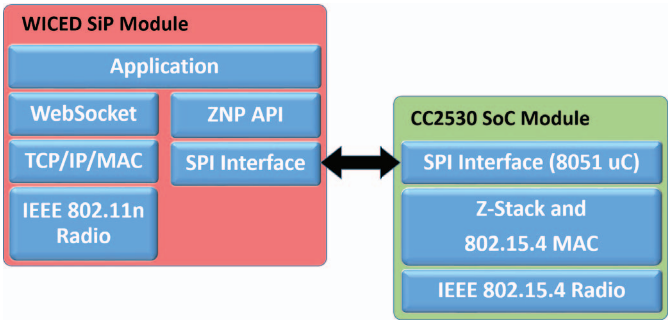


Fig. 2. LR-WPAN embedded IP gateway system architecture: WICED host MCU and CC2530-ZNP combination.

GHz WiFi module doesn't have any coexistence issues. The problem occurs when both of them use the same 2.4 GHz band. If we think about using 2.4 GHz band for both ZigBee and WiFi, we have to consider co-channel interference which will increase PER and retransmissions. In [13][14][15], researchers analyzed coexistence of WiFi and ZigBee technologies by applying several coexistence scenarios in a home environment.

### B. WSAN Devices and Network Coding

To form a wireless sensor-actuator network (WSAN) environment, multipurpose WSAN nodes are developed in the study. These nodes are equipped with relays and sensors, making it possible to connect them on any kind of electrical device for turning it on and off, collecting data from its environment etc. ZigBee network processor in combination with ARM Cortex-M3 microcontoller is used for LR-WPAN communications part. Network coding is proposed and implemented between ZigBee nodes including embedded IP gateway. Because of the variable topology property of WSNs, random network coding is the most appropriate technique for increasing reliability, throughput and battery life for WSN devices. Figure 3 denotes ZigBee WSAN.

The core idea of network coding is to allow scrambling data at intermediate nodes [5] by generating a linear combination of the incoming packets.

Consider the butterfly network shown in Figure 4. Simply addition of the bits of incoming packets in $GaloisField(2)$ for coding purposes means bitwise XOR. For practical consideration, the Relay node in the middle uses XOR operation for encoding the packets while Sink-1 and Sink-2 nodes use XOR operation for decoding the packets.
Let's take the network coding operation more officially. Consider original packet A as:

$$\mathbf{A} = \{A_1, A_2, ..., A_k\} \tag{1}$$

Choosing coding coefficients randomly, the encoding vector can be represented as:

$$\mathbf{e} = \{e_1, e_2, ..., e_k\} \tag{2}$$

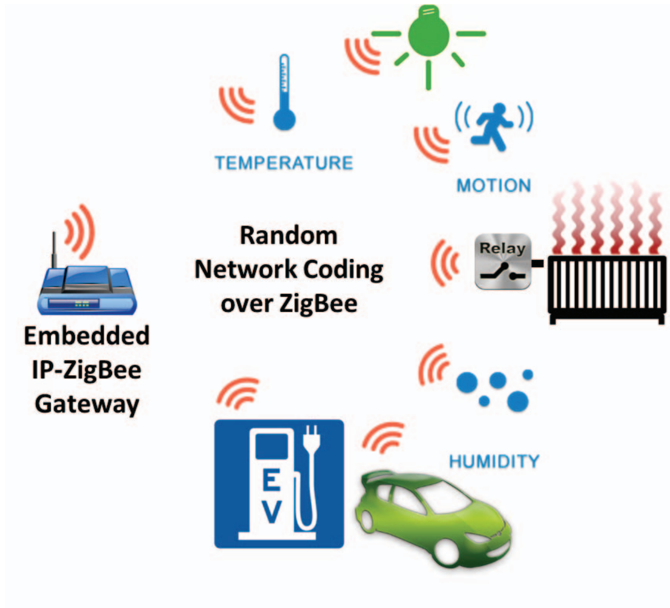


Fig. 3. Random network coding over ZigBee WSAN and smarthome sensors and actuators.

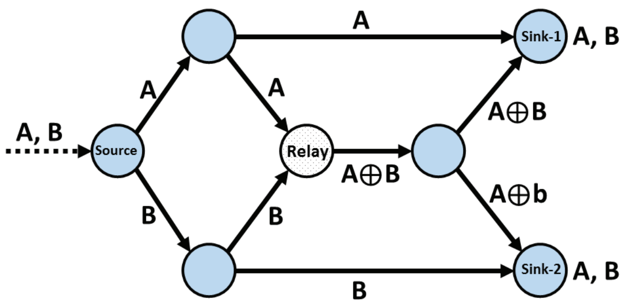


Fig. 4. The butterfly network. Each directed link in this network is capable of transferring a single packet in one cycle. There are 2 data packets, A and B, which must be transferred to the Sink-1 and Sink-2 nodes.

We can generate the linear combination of incoming packet A in relay node and transmit it to the sink node:

$$\mathbf{X} = e_1A_1 + e_2A_2 + ... + e_kA_k \tag{3}$$

Considering the packet recovery problem from receiver side, let's denote the received packet $R_i$ in the $i^{th}$ transmission cycle as:

$$\mathbf{R_i} = \{a_{i1}A_1 + a_{i2}A_2 + ... + a_{ik}A_k\} \tag{4}$$

Receiver gets the coded packets successively and keeps a received packet matrix:

$$\mathbf{R} = \begin{bmatrix} a_{11}A_1 & a_{12}A_2 & . & . & a_{1k}A_k \\ a_{21}A_1 & a_{22}A_2 & . & . & a_{2k}A_k \\ . & . & . & . & . \\ . & . & . & . & . \\ a_{k1}A_1 & a_{k2}A_2 & . & . & a_{kk}A_k \end{bmatrix}$$

Applying Gaussian elimination method to the received packet matrix, we can achieve a solvable linear system. Then it becomes easy to obtain recovered message array $A_r$:

$$\mathbf{Ar} = \{Ar_1, Ar_2, ..., Ar_k\} \tag{5}$$

### C. Service-Oriented Cloud Architecture

To enable these end devices to send and receive data over the Internet, we need to define overall system architecture including cloud side. By definition, IoT paves the way for pervasive scaling of Internet enabled devices. Therefore, it should have expandable structure in the aspect of both simultaneously served devices and number of associated services to those devices. Furthermore, service oriented architecture [3][4] design pattern should be applied for the efficient scaling of the value added services (VAS) cloud analytics. The architecture that meets all of those needs is defined in Figure 5.

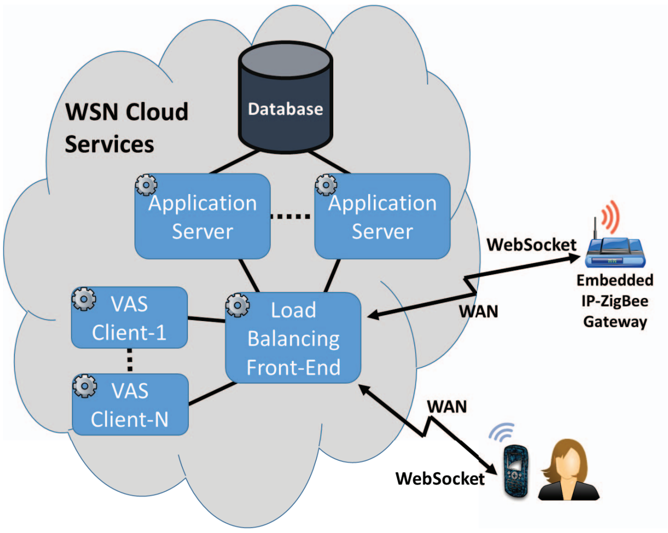


Fig. 5. Expandable overall system architecture including value-added cloud services.

On the right hand side of Figure 5, IoT device side implementation is represented by a smarthome sensor network. There is a gateway node in between LR-WPAN sensors and IP network infrastructure. Regardless of LR-WPAN and wide area network (WAN) protocols, there must be a kind of packet routing and forwarding mechanism in between. On the left hand side, proposed system for IoT cloud side is shown. This architecture is implemented for testing the operation of LR-WPAN network coding mechanism.

### D. Cloud Data Analytics

Data analytics is not a new concept but it changed its shell with emerging WSN and IoT applications. With the increase in the number of sensors, more and more data is now collected each and every second. Smart sensing and actuation started to be used for agriculture and stockbreeding, home security, smart diagnosis, vending machine and production automation applications. The need of distinguishing useful data from this big data collection emerged and data mining techniques started to be implemented for the cloud analytics. The service oriented cloud architecture proposed in this study takes those cloud applications as value added services and optimizes the cloud architecture according to the requirements of massive scaling nature of WSNs.

## IV. Conclusion

In this study, new and promising technique, random network coding, is proposed to the WSN applications using LR-WPAN ZigBee protocol. Embedded IP gateway is realized with a combined node using ZigBee and WiFi embedded modules. Low overhead, low latency and low resource WebSocket protocol is used between embedded gateway and cloud applications server. Service-oriented design is proposed and implemented to the cloud services, enabling incremental system scaling for increasing number of sensor devices and related value added services.

WSN and IoT ecosystem will form the future of networked society. The proposed system architecture is highly applicable for smart-home, smart-office, smart-grid and smart-city applications with integrated value added services. Utilization of decreased transmission cycles as an outcome of network coding techniques and efficient service-oriented system architecture provides both manageability and multiplatform compatibility to future WSN applications.

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