

Fiber-wireless for smart grid: A survey

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Abstract. Smart grid allows two-way communication between power utility companies and their customers while having the ability to sense along the transmission lines. However, the downside is such, when the smart devices are transmitting data simultaneously, it results in network congestion. Fiber wireless (FiWi) network is one of the best congestion solutions for smart grid up to date. In this paper, a survey of current literature on FiWi for smart grid will be reviewed and a testbed to test the protocols and algorithms for FiWi in smart grid will be proposed. The results of number of packets received and delay vs packet transmitted obtained via the testbed are compared with the results obtained via simulation and they show that they are in line with each other, validating the accuracy of the testbed.

1 Introduction

An interconnected network that is used to deliver electricity from suppliers to consumers is what is called as “electrical grid”. It works in a way where electrical power is produced at the generating stations to be carried to demand centers via high-voltage transmission line and further to individual customers via distribution lines.

Despite of being an engineering marvel, to date electrical grid is being stretched to its capacity. This is due to the population growth and more modern electrical appliances are being added in every household, such as high-definition televisions, laptops and wireless telephones. These modern appliances are more sensitive to variations in electric voltage causing the entire electric grid to be overused and fragile.

Therefore, an improved electricity supply chain that is called as “Smart Grid” is being introduced to maximize the throughput of the system while reducing the energy consumption. Figure 1 shows the differences between conventional electrical grid and Smart Grid where additional features are introduced in Smart Grid such as monitoring, analysis, control, and communication capabilities. Devices located along the power lines and on premises are able to interact with each other, allowing for two-way communication between utility and customers. Hence, Smart Grid is able to respond digitally to the ever-changing electric demand.

The term used to denote an automated two-way communication between a smart meter and a utility data center is called as Advanced Metering Infrastructure (AMI). AMI uses bidirectional communication to

provide energy management data such as consumption data and outage reports as well as control information data such as alerts and equipment settings.

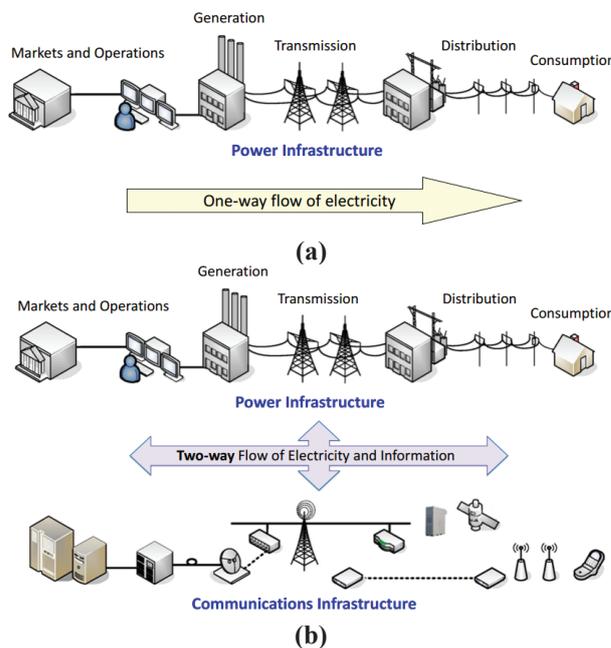


Fig. 1. a) Conventional electric grid b) Smart Grid

AMI comprises of four tiers; home network, smart meter, concentration point and utility data centre. In home network, Home Area Network connects smart appliances to a smart meter for data collection to measure real time energy consumption. The collected data from smart meter then traverse to a concentration point such as substation or communication tower as part of smart grid. Afterwards, data flows from concentration point to the metering data management systems (MDMS) located in utility data centre via private

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network. The MDMS will then process and manage data on energy consumption and fault detection.

However, the downside of Smart Grid is such, when the smart devices are transmitting data simultaneously, it results in network congestion [1]. Challenges occur in ensuring the reliability and timeliness of the data transmitted over these networks. Therefore, advance techniques such as cognitive radio [2] and fiber wireless (FiWi) are developed to fully utilize the capability of smart grid wireless networks.

Cognitive radio networks allow unlicensed devices to transmit in unused “spectrum holes” in licensed bands without causing harmful interference to authorized users. It configures the radio for different combinations of protocol, operating frequency, and waveform. However, cognitive radio needs to deal with two primary issues which are hidden primary users [3] and spread spectrum primary users [4], both of which lead a cognitive radio to incorrectly decide that a spectrum block is empty. Hence, it has higher probability to cause the signals to interfere with the licensed primary user.

This does not happen with FiWi as the optical side is able to provide reliable transmission for smart meter and intelligent sensor data, while the wireless side allows flexible access to remote locations and broad coverage. Therefore, this paper discusses in details on the integration of FiWi and smart grid. The remainder of this paper is structured as follows. Section 2 introduces the fundamental of FiWi networks. The state of the art of FiWi networks in smart grid is then reviewed and we highlight selected FiWi testbeds in the literature. We introduce our proposed testbed in the next section and the final section concludes the paper.

2 Fundamental FiWi Networks

FiWi is an integration between fiber and wireless network that is also known as the endgame for the broadband access network. Fiber and wireless are combined together to achieve high bandwidth as well as mobility in the network.

Typical architecture of FiWi is depicted in Figure 2, where the wired side consists of a basic configuration of Passive Optical Network (PON) as it is the dominant broadband access network emerging up to date. FiWi consists of Optical Line Terminal (OLT) at the central office that is connected to multiple Optical Network Units (ONUs) at the customer’s sides via optical fiber and passive optical splitter. The ONUs are further connected to end users wirelessly.

PON for FiWi at the wired side can generally be divided into two types; Wavelength Division Multiplexing (WDM) and Time Division Multiplexing (TDM) PON. WDM PON allows each ONU to operate at a different wavelength to avoid collision. In order to

receive the data transmitted in multiple channels, a tunable receiver or a receiver array is required at the OLT. It also requires each ONU to use a fixed transmitter operating at a different wavelength, which would result in an inventory problem. Although the inventory problem can be solved by using tunable transmitters, these devices are costly, making the solution cost-ineffective.

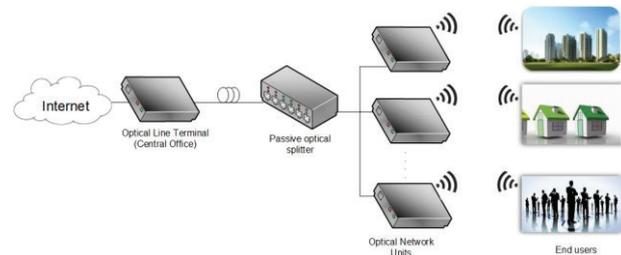


Fig. 2. FiWi architecture

On the other hand with TDM, OLT allocates a time slot or a transmission window for data transmission in ONU. Upon the arrival of its time slot, the ONU will send out its buffered packets at the full transmission rate of the upstream channel. If there are no frames in the buffer to fill the entire time slot, idles are transmitted. TDM is considered as cost effective approach but the arbitration mechanism is more complex compared to WDM.

The two most popular wireless technology used in FiWi are WiFi and WiMax. WiFi that is using IEEE Standard 802.11 offers low bandwidth; 54Mbps for IEEE 802.11a whereas 11Mbps for 802.11b and 54Mbps for 802.11g. The range is also limited, typically up until 100m, which is why it is mainly used for wireless local area networks. In WiFi, central authority known as access point is required to manage the network. It is gaining its popularity due to its flexibility to multihop.

On the other hand for WiMax, IEEE Standard 802.16 is used. WiMax provides high bandwidth up to 75Mbps in a range of 3 to 5km. However, as the distance gets longer, the bandwidth reduces to 20-30Mbps due to the fact that WiMax does not work proficiently for non-line-of-sight communications. WiMax is typically used for metropolitan area networks with base station is required to manage the network. The downside is such, WiMax is more suitable for single hop.

Data is transmitted in FiWi networks via these two techniques; Radio over Fiber (RoF) or Radio and Fiber (R&F). RoF is a technique where radio signals are transmitted over optical fiber to provide communication service. It is an analog communication scheme where the signals are simply converted from electrical to optical and vice versa. One of the advantages of RoF is that only minimal modifications are required at the base stations or access points since Radio Frequency (RF) signals are transmitted to remote antenna as it is.

On the other hand for R&F, different media access control (MAC) protocols are used in fiber and wireless link. Although it requires major modifications at base stations or access points, since it uses two different protocols for two different links, it solves the problems caused by insertion of the optical distribution system in wireless networks.

For FiWi in smart grid, different combination of techniques are used at the fiber link, wireless link and for data transmission. The combinations are discussed in the following section.

3 State of Art

3.1 FiWi for Smart Grid

To date, there are still very limited literature on utilizing FiWi for smart grid. Among the earliest paper on FiWi for smart grid found in the literature is Uber-FiWi published 2011 by Maier et al. [5]. Uber-FiWi combines a big fiber ring network at the wired side to interconnect the distribution management system to either EPON network (for urban area) or WiMax base station (for suburban or rural area). Total power consumption and total cost of various scheduling algorithms are studied using this hybrid network.

In 2013, Zaker et al. [6] has proposed a Fiber-Wireless Sensor Networks (Fi-WSN) gateway design for smart grid. In the design proposed, TDM Ethernet PON (EPON) serves as back-end of the communication network whereas the WSN forms the front-end. Due to the fact that data in smart grid needs to be treated differently as according to their urgency, an algorithm has been proposed in the paper to allow differentiation between high priority and low priority packets.

In 2014, Ghassemi et al. [7] has proposed the usage of RoF networks for smart grid. RF signals are distributed from a control unit called headend (or OLT) to remote antenna units (RAU) (or ONU) so that the complex signal processing functions (for modulation, synchronization, multiplexing, coding, etc.) are centralized. This simplifies RAU and has greatly reduced the system installation and operational cost. This system can be used for both TDM and WDM PON as well as for both WiFi and WiMax technology.

As can be observed, there are still limited researches done in studying FiWi for smart grid as FiWi is still considered as a new technology. Due to this reason, a reconfigurable FiWi testbed is needed to study the best protocols, algorithms and topology for smart grid.

3.2 FiWi Testbed

Numerous FiWi testbed are developed for various reason ranging from evaluations, comparison, review and

enhancement. Digitized RoF FiWi testbed has been developed in [8] where the equipment used are modulated vertical cavity laser, wireless signal generator, digitized sampling oscilloscope, photodetector, digital to analog converter, arbitrary waveform generator and vector signal analyser.

Pang et. al [9] proposed a FiWi testbed, which transmits on W-Band, between 75-110 GHz frequency band. The testbed proposed uses hardware such as 16 QAM optical baseband transmitter, 100GHz photodetector, Erbium-doped fiber amplifier, W-Band horn antenna, low-noise amplifier, W-band balance mixer, local oscillator, Rohde and Schwarz signal synthesizer, analog to digital converter and digital signal processing-based receiver.

Both digitized FiWi testbed and W-band testbed are purely hardware-based testbed. With purely hardware-based testbed, it is not easy to reconfigure the testbed to study on the protocols and algorithm, making it less suitable to be used in FiWi for smart grid study.

There are also implementations of network virtualization in the FiWi. Network virtualization is a combination of hardware and software. Dai et. al [10] applies network virtualization to hide the differences between fiber network to the wireless network. In terms of software, the testbed contains virtual resources that provides bandwidth, computing capacity, storage and virtual networks.

Meng et. al [11] proposed a Modified Weighted Round Robin (MWRR) algorithm based on the model of FiWi network virtualization and this testbed uses MATLAB as their programming platform.

However, since network virtualization is partially software-based testbed, it is not able to capture some of the non-linearization effects.

Lim et. al [12] proposed a testbed incorporating liquid-crystal-on-silicon (LCoS)-based programmable optical processor (POP) in the remote node to study the performance of WDM-based 60 GHz millimetre FiWi link. This testbed uses programmable tools where the POP is flexible, robust and enables simple future system upgrade. POP used in this testbed is to de-multiplex the interleaved channel before distributing to base station with error free transmission. Although POP is a programmable module, however its application only limited at the remote node and not the overall FiWi network architecture.

A fully fast reprogrammable FiWi testbed is needed to study the most suitable protocol and algorithm in smart grid network. The next section discusses on a proposed FiWi testbed that uses software defined radio (SDR) to make it fast reconfigurable, simple and scalable.

4 Fast Reconfigurable FiWi Testbed

Figure 3 shows the fast reconfigurable FiWi testbed proposed where the major components used are SDRs for OLT, ONU and end users. We chose SDR as the main component of our testbed as it has the ability to support multiple functionality simply by modifying the software without the need of changing the hardware, making the study of protocols and algorithms to be simpler, faster and cost savvy.

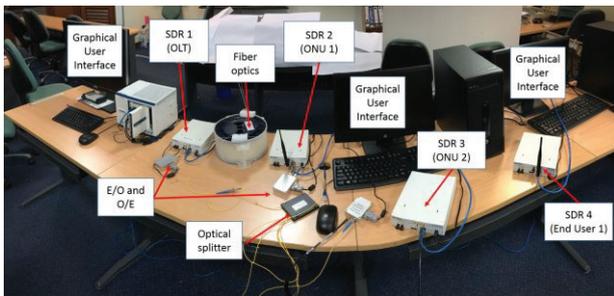


Fig. 3. FiWi Testbed Proposed

The SDR chosen for our testbed is Universal Software Radio Peripheral (USRP) by National Instrument (NI). A wide range of USRPs is available in the market, but we have chosen USRP-2922 particularly as it meets our testbed requirements which are to transmit at 2.5GHz frequency band and to have simultaneous transmit/receive feature.

The USRP that acts as OLT is first connected to electrical/optical converter before it goes to the 20km single mode fiber spool, then to a passive optical splitter to split the data into multiple ONUs. From the splitter, the data needs to go through an optical/electrical converter before it is connected to USRP that acts as the ONUs. From ONU's USRP to end users' USRP, antenna are needed as the transmission is done wirelessly.

Every SDR is further connected to a computer equipped with a Graphical User Interface (GUI) as shown in Figure 4 to monitor traffics coming in and out. The study of protocols and algorithms require the program to be modified via Labview at affected USRP without having to modify the hardware and the results can then be observed at the GUIs. Among the parameters that can be obtained are throughput, delay and jitter.

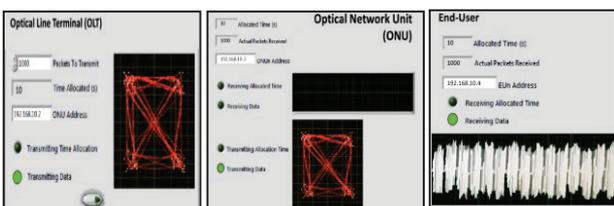


Fig. 4. Graphical User Interface

Figure 5 shows number of packets transmitted versus number of packets received using static bandwidth allocation algorithm implemented in this

FiWi testbed. It shows that up until 11,000 packets are received for both methods via simulation and via testbed, validating the results achieved using our FiWi testbed.

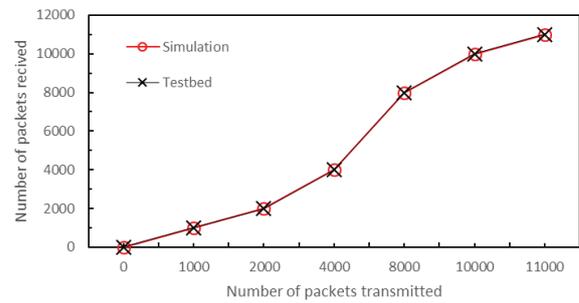


Fig. 5. Number of packets received vs number of packets transmitted via simulation and testbed

Figure 6 shows number of packets transmitted versus delay using static bandwidth allocation algorithm implemented in this FiWi testbed. It shows that with both method, delay increases as the number of packets transmitted increases and the results via simulation and testbed are in line with each other.

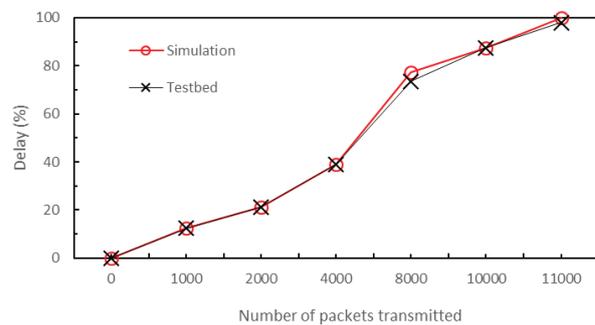


Fig. 6. Number of packets transmitted vs delay for simulation and testbed

5 Conclusion

In this paper, we have introduced the fundamental of smart grid and FiWi networks and we have reviewed the state of art of FiWi networks for smart grid as well as selected FiWi testbed. We have also introduced our proposed fast reconfigurable FiWi testbed with the number of packets received and delay results, which show that the testbed is validated as the results obtained via simulation and testbed are in line with each other.

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