Communication Network of Wide Area Measurement System for Real-Time Data Collection on Smart Micro Grid

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Abstract This paper deals with communication architecture employing appropriate communication technologies for distribution side Wide Area Measurement System (WAMS). The different communication technologies like WiredLAN, WLAN, ZigBee protocol are simulated in ns2 considering a 5-bus smart micro-grid topology and the performance metrics are compared and analysed based on the standard requirements in order to suggest the apt technology. The study shows that in comparison with a homogeneous network, a heterogeneous network provides a better result considering the operational demands at different levels of the smart distribution grid architecture.

Keywords WAMS · Smart grid · Communication technologies

1 Introduction

The conventional power system faces many significant challenges like meeting the demand of energy, environmental issues, deregulation, security issues and integrating renewable and distributed sources to the system. To overcome these challenges the existing power system needs to undergo considerable amount of change. To ensure that the system stability is maintained even in the heavily loaded conditions real-time measurements must be taken from throughout the grid. These measurements must be taken in a distributed as well as synchronised manner. This is achieved through Wide Area Measurement System (WAMS) [1]. WAMS provides real-time knowledge of various issues and events as and when they occur. This on-time warning helps the operators in taking the necessary control action. In the transmission side of the grid Phasor Measurement Units (PMU) are used to take the real-time measurements [1]. With the help of a GPS unit the real-time data taken

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by the distributed PMUs are synchronised [1]. For real-time monitoring in distribution side Real-Time Data Collection Units (RTDCU) [2] are introduced to mimic the synchronized and distributed real-time data collection of PMU. The data collected by the RTDCUs are transmitted to the server either directly or via a Data Concentrator (DC). A reliable communication system, which enables this message passing, forms the backbone of WAMS [1].

This paper focuses on developing communication architecture for WAMS in smart distribution network focusing on the selection of communication technologies that can be used for data transmission. The selection of the communication technology depends on many performance indices like delay, bandwidth, throughput, cost, packet delivery ratio, etc. A suitable communication technology has to be selected for the distribution side WAMS by comparing the performance of various technologies for the selected topology. Different communication technologies are simulated in a network simulator for a selected topology for the 5-bus smart micro-grid laboratory simulator [3] and their performance metric values are compared, based on which the selection of the communication technology is done.

The paper consists of three sections. The second section gives an overall idea about the WAMS and the different communication technologies used in WAMS. The next section deals with the system description and then finally the results and conclusion.

2 WAMS for Distribution System

As the real-time condition of the grid changes dynamically with dynamic variations in supply and demand, WAMS began playing a significant role in acquiring the real-time status of the grid as well as maintaining its stability. WAMS helps in monitoring the grid in a more real-time and synchronous manner [2]. In the earlier stages SCADA was used in WAMS for taking measurements. SCADA has a few drawbacks like measurements taken are analogue, has a low resolution of 2–4 samples per cycle, dynamic observability is not possible and the measurements taken are not synchronised [4]. To overcome these drawbacks faced by SCADA, PMU was introduced. In PMU the measurements taken are digital in nature, the resolution increased to a maximum of 60 samples per cycle, the observability became dynamic in a wide range and the measurements are taken in a synchronised manner which helped in knowing current status of the grid. By introducing a GPS unit to the PMUs, synchronised data acquisition with time stamp was made possible. The PMUs are deployed in the transmission side of the grid [2]. For a similar function in the distribution side RTDCUs can be used [2]. For streaming of the data collected by the RTDCUs to the server a reliable communication system is needed. The communication system of WAMS for distribution side is responsible for the transmission of data from RTDCUs to the server and the control messages from the server to the RTDCUs. The selection of the communication technology mainly depends on lot of factors like performance of the communication technology, requirements from power system, operational conditions, etc. A few of the characteristics that are considered for the selection of the communication technologies are delay, bandwidth, throughput, packet delivery ratio, etc. [5–8]. Delay is the time taken to deliver the message at the destination from the source. For transmitting data from RTDCU to DC the delay should be within a range of 20–50 ms [9]. But in real-time applications it can go up to 10 s [9]. Throughput is the number of bits transmitted per second expressed in kilobits per second. The RTDCU has to transmit 10–60 frames per second [9]. Since in WAMS data being transmitted is of a large size, the communication technology selected from RDTCU to DC should have a minimum bandwidth of 25.39 kbps [9] and the communication technology selected from DC to server should have even a higher bandwidth because the DC collects the measurements from many RTDCUs and transmit it to the server; so the data size increases. To transmit data in the transmission side of the grid PMUs rely mainly on fibre optic communication [10]. Implementing fibre optic communication in a power distribution network results in high infrastructure and deployment cost because of the large number of nodes that are part of the network. Also latency increases when using fibre optic communication [10]. Depending upon the scenario either the same communication technology can be used throughout the different links of the communication network creating a homogenous communication system or a combination of technologies can be used at different links of the communication network creating a heterogeneous communication system. The different communication technologies that are available are Wired LAN, WLAN, ZigBee protocol, WiMaX, Optical Fibre, PLC, etc. [5, 11].

There are different software simulators using which the communication technologies can be simulated for the required application and their performance metrics can be compared. A few of the software simulators available are ns2, ns3, OPNET, OmNet++, GNS3, Qualnet, etc. [12, 13].

3 System Description

The block diagram depicted in Fig. 1 gives an overall idea about the different communication scenarios that are needed in the smart distribution grid. The smart metres are used to collect data from the consumers. The data collected by the smart metres are either transmitted directly to the cloud or via a data collector depending on the distance of the smart metre from the cloud gateway. The RTDCUs are employed to take the real-time measurements from the primary distribution side of the grid. The data from the RTDCUs are also sent to the cloud for analysis. Based upon the data received and analysed the cloud takes necessary control actions which is implemented in real time by the different control units. For distributed decision-making cloud computing is used [14].

Figure 2 is a schematic representation of the communication system of WAMS for smart distribution network. The real-time data collected by the RTDCUs are

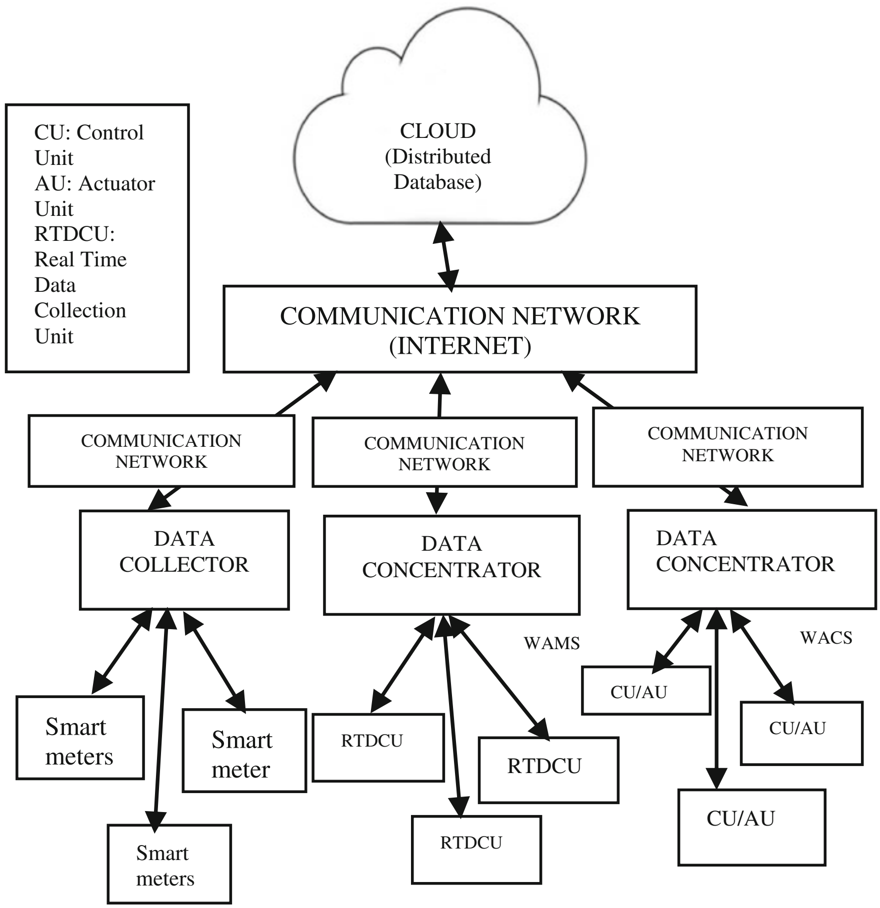

Fig. 1 Communication scenario in a smart micro-grid

transmitted to the cloud. Depending upon the position of the RTDCU the data is either sent directly or through a DC.

The DC accumulates the data received from different RTDCUs and sends it to the cloud. In the cloud the data will be analysed. The cloud sends command messages back to the RTDCUs. These commands can be messages asking the RTDCU to start transmitting the data or stop transmitting the data or asking the RTDCU to vary the time interval between the consecutive data messages [9]. Hence an efficient bidirectional communication is necessary for the proper monitoring and control of the grid.

Figure 3 depicts the topology of the WAMS system being implemented in the laboratory model of a 5-bus smart micro-grid [3, 13]. The server is kept at the centre since it will be equidistant from all nodes. The DCs are placed nearer to server because the size of the data being transmitted will be large when it reaches near the server.

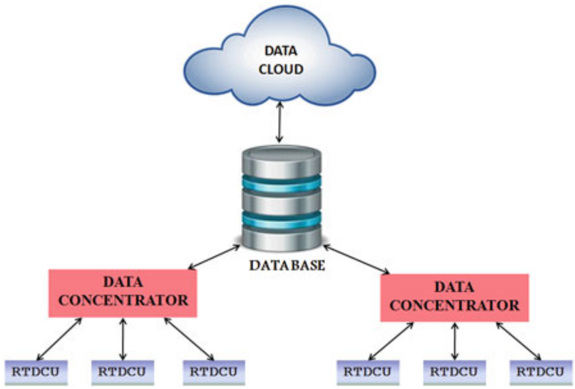

Fig. 2 WAMS communication system

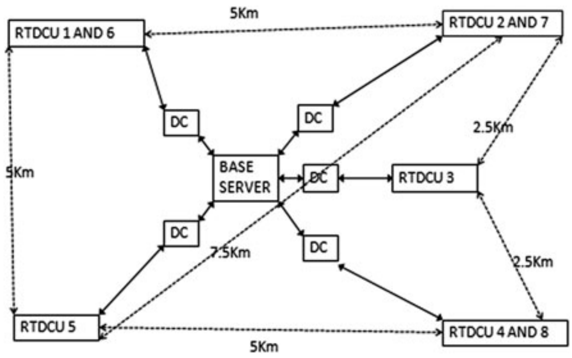

Fig. 3 Topology of the communication network

4 Simulation Results

Different available communication technologies for the implementation in a 5-bus smart micro-grid are PLC, Bluetooth, ZigBee protocol, WiredLAN, WLAN, etc. Due to restriction or overhead posed by several communication technologies, only WiredLAN, WLAN and ZigBee protocol are selected for simulation in ns2 [1, 5]. Communication technology was selected considering the performance metrics delay, throughput and packet delivery ratio.

The communication scenario in this selected topology can be divided into two segments. First, the communication from RTDCU to DC and second the communication from DC to server. The communication between all RTDCU-DC pair is similar, the only difference being the distance from each RTDCU to its corresponding DC. The performance metrics like delay, throughput and packet delivery ratio was analysed for the communication link between RTDCU-DC, DC-server and for the overall topology.

Table 1 Simulation result for WiredLAN

	Throughput (kbps)	Delay (ms)	Packet delivery ratio
DC to Server	12849.92	3.50372	74.56

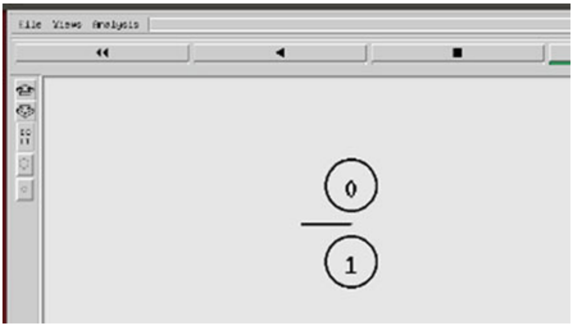

Fig. 4 Simulation of WiredLAN in ns2

Table 1 contains the performance metrics for WiredLAN. Since implementing WiredLAN in a new area over large distance causes unnecessary overhead in infrastructure and deployment cost, the performance metrics for WiredLAN was found out only from DC to server. Figure 4 depicts the simulation of WiredLAN from DC to server.

Table 2 contains the simulation result of ZigBee protocol. ZigBee protocol is based on low power transmission. By analysing the results obtained it is observed that ZigBee protocol has the required range and the throughput and delay obtained are within the satisfactory range. Figure 5 shows the simulation of ZigBee protocol in the overall topology.

The simulation results of WLAN are tabulated in Table 3. The delay for the data being transmitted from RTDCU to DC in each link was found to be outside the desired limit. So WLAN was not simulated in the overall topology. Figure 6 shows the simulation of WLAN in a single link.

Table 2 Simulation result for ZigBee protocol

	Throughput (kbps)	Delay (ms)	Packet delivery ratio	Number of intermediate nodes
Server to DC	1456.42	2.4133	75.02	0
RTDCU1 to DC	2021.63	3.94	74.48	3
RTDCU2 to DC	2299.40	3.441	75.05	3
RTDCU3 to DC	3743.59	2.0133	76.61	0
RTDCU4 to DC	1723.84	2.519	74.27	2
RTDCU5 to DC	2123.35	4.158	76.04	3
Overall topology	48807.4	18.19	76.28	11

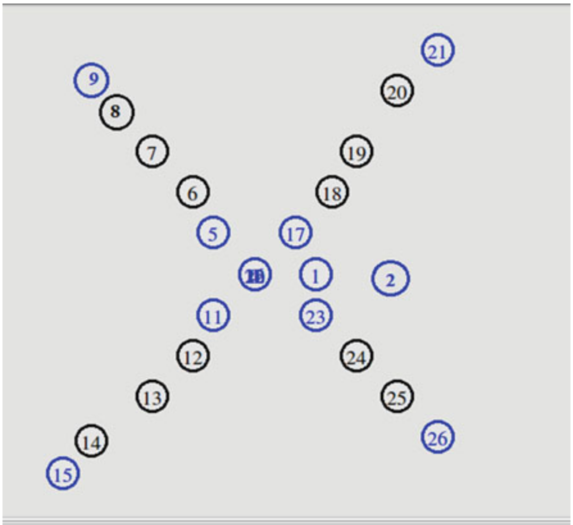

Fig. 5 Simulation of ZigBee protocol in ns2

Table 3 Simulation result for WLAN

	Throughput (kbps)	Delay (ms)	Packet delivery ratio	Number of intermediate nodes
Server to DC	612	218.36	86.90	5
RTDCU1 to DC	1742.06	230.29	85.10	16
RTDCU2 to DC	1643.28	230.32	86.90	17
RTDCU3 to DC	600.22	218.11	86.64	5
RTDCU4 to DC	1642.46	230.15	86.90	13
RTDCU5 to DC	1763.05	237.92	86.64	21

ZigBee protocol has more range when compared to WLAN. So the number of intermediate nodes decreases in case of ZigBee protocol. It can be seen that WLAN has more throughput than ZigBee protocol but the bandwidth of ZigBee protocol satisfies the WAMS requirement. The delay of WLAN is more than that of ZigBee protocol. So ZigBee protocol is an apt technology to be implemented from RTDCU to DC. The main requirement for the selection of communication technology from DC to the server is that it should have high bandwidth because the size of the data increases and the loss of data must be restricted up to a certain point. Also the data must be delivered within the required frame of time. From the performance metrics tabulation it can be seen that WiredLAN has the largest bandwidth when compared

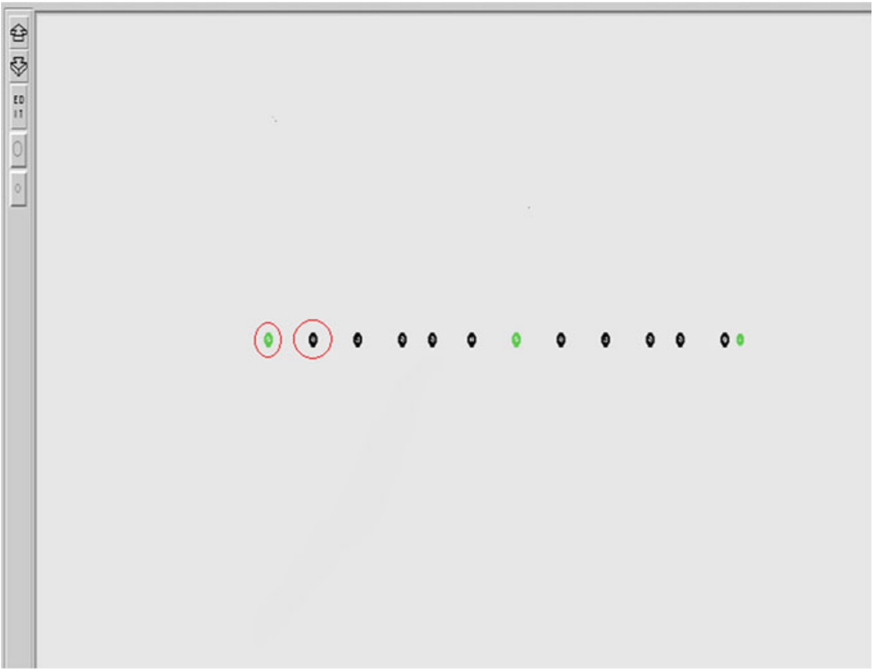

Fig. 6 Simulation of WLAN in ns2

Table 4 Simulation result for heterogeneous communication system

	Throughput (kbps)	Number of intermediate nodes
Server to DC	12812.92	0
RTDCU1 to DC	104.06	3
RTDCU2 to DC	104.28	3
RTDCU3 to DC	60.22	0
RTDCU4 to DC	104.46	2
RTDCU5 to DC	106.05	3

to ZigBee protocol and WLAN. Also WiredLAN delivers data within the desired time. So WiredLAN can be implemented from DC to server. A combination of ZigBee protocol and WiredLAN is best suited for implementation in the topology that has been selected. The heterogeneous communication was simulated in ns2. The delay was found to be 15 ms and throughput was within the desired range. Table 4 contains the performance metrics of the heterogeneous system. Figure 7 shows the simulation of the heterogeneous communication in ns2.

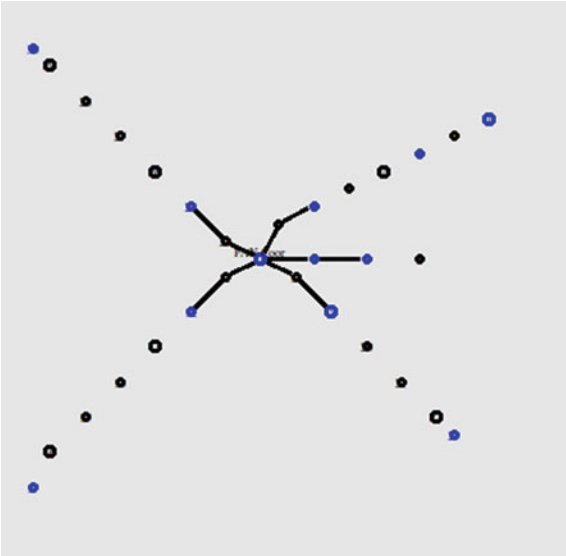

Fig. 7 Simulation of heterogeneous network in ns2

5 Conclusion

Different communication technologies like WiredLAN, WLAN and ZigBee protocol were simulated in ns2 considering a 5- bus smart micro-grid topology and the results were analysed. It was analysed that due to physical constraints, WiredLAN could not be implemented from RTDCU-DC, however, it serves as one of the better options to be implemented from DC-server. From the simulation results it was evaluated that WLAN was not able to meet requirements set by the performance metrics. ZigBee protocol meets all the criteria set by the performance metrics in RTDCU-DC link but due to low bandwidth does not satisfy the bandwidth requirement from DC-server. In comparison with a homogeneous network, a heterogeneous network provides a better result. Hence a heterogeneous network comprising of ZigBee protocol from RTDCU-DC and WiredLAN from DC-server is proposed for the selected topology.

This work can be further extended by analysing the data received at the server and taking the necessary control action thereby developing a wide area monitoring, protection and control system for distribution side automation. Also all the messages transmitted by the RTDCU can be standardised based on IEEE C37.118 standards.

References

1. Sahraeini M, Javidi MH. Wide area measurement systems. In: Md. ZahurulHaq, editor. Advanced topics in measurements.
2. Nithin S, Sivraj P, Sasi KK, Lagerstom R. Development of a real time data collection unit for distributionnetwork in a smart grid. International conference on power and energy systems: towards sustainable energy, ASE Bangalore, India, 15 March 2014.
3. Nithin S, Sasi KK, Nambiar TNP. Development of smart grid simulator. Proceedings of national conference on power distribution, CPRI, India, 2012.
4. Singh B, Sharma NK, Tiwari AN, Verma KS, Singh SN. Applications of phasor measurement units (PMUs) in electric power system networks incorporated with FACTS controllers. Int J Eng Sci Technologym. 2011;3(3):64–82.
5. Güngör VC, Sahin D, Kocak T, Ergüt S, Buccella C, Cecati C, Hancke GP. Smart grid technologies: communication technologies and standards. IEEE Trans Ind. Inf. November 2011;7(4):529–539.
6. Gajrani K, Sharma KG, Bhargava A. Performance assessment of communication network in WAMS. Int J Distrib Parallel Syst (IJDPS). November 2012;3(6).
7. Eissa MM, Allam AM, Mahfouz MMA, Gabbar H. Wireless communication requirements selection according to PMUs data transmission standard for smart grid. IEEE international conference on smart grid engineering (SGE'12). 27–29 August 2012, UOIT, Oshawa, ON, Canada.
8. Kansal P, Bose A. Bandwidth and latency requirements for smart transmission grid applications. IEEE Trans Smart Grid. September 2012;3(3):1344–1352.
9. Martin KE, Hamai D, Adamiak MG, Anderson S, Begovic M, Benmouyal G, Brunello G, Burger J, Cai JY, Dickerson B, Gharpure V, Kennedy B, Karlsson D, Phadke AG, Salj J, Skendzic V, Sperr J, Song Y, Huntley C, Kasztenny B, Price E. Exploring the IEEE Standard C37.118–2005. Synchrophasor for Power Systems. IEEE standards, October 2008.
10. Phasor Measurement Unit. http://en.wikipedia.org/wiki/Phasor_measurement_unit#Phasor_networks.
11. Gungor VC, Lambert FC. A survey on communication networks for electric system automation. Comput Netw. 2006;50:877–897.
12. Chhimwal MP, Rai DS, Rawat D. Comparison between different wireless sensor simulation tools. IOSR J Electron Commun Eng (IOSR-JECE). March–April 2013;5(2):54–60.
13. Sarath TV, Sivraj P. Simulation and analysis of communication technology for a smart grid framework. International conference on communication and computing. Elsevier Publications; 2014.
14. Simmhan Y, et al. Cloud-based software platform for data-driven smart grid management. IEEE/AIP computing in science and engineering; 2013.