ICT Enabled structural and functional convergence in public utilities: Energy distribution, telecommunications and cloud computing

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Abstract

ICT through the Internet is being integrated into the structure and function of essential public utilities such as electrical power grids and telecommunication networks where it is having a transformative effect, both on the Internet itself and on the integrated public utility. From its initial function of providing global data flow between applications on computers, the Internet is now being used to connect all kinds of processor-enabled machines and is referred to by some as the Internet of Things (IoT). Within the penetrated public utilities, there is movement of "intelligence" from the utility core network to intelligent devices located at peripheral or distributed points, particularly at network end-points in the case of VoIP phones. Intelligence refers to the theoretically unlimited capacity of software to control processor-enabled devices thereby vastly increasing the range of end-user telecommunication services provided, of providing self-regulation and healing in response to critical situations (Smart Grid) and of providing access to corporately owned processing power (Cloud Computing).

Key words: Internet**,** public utilities, intelligence, cyber-physical, intelligent network, smart grid, telecommunications, cloud computing.

Introduction

An electric power grid is an important example of a public utility requiring monitoring and regulation to ensure reliability and efficient energy delivery. It typically consists of a geographically dispersed generation, transmission and distribution power line infrastructure in need of efficient management and control (Shoemaker & Mack, 2012). This essential public utility, meeting ever increasing energy demands for industrial and domestic use, needs constant and remote monitoring to ensure reliability of service delivery and to avoid system or power outages which can lead to cascading blackouts as a failing subsystem seeks the services of another which in turn is overloaded and fails. Such failures incur significant economic and opportunity costs on the national economy. These are worst case scenarios in present day power systems characterized by often aging infrastructure attempting to service ever increasing peak demands in load centres thereby placing systems under stress. Centralized and distributed monitoring via communication networks can be used to detect levels of voltage and current deemed to be outside specified safe ranges thus indicating impending system failure.

This paper seeks to explore the present transformation of public utilities, such as the power grid, which is occurring in new developments emerging from the integration of Information Communication Technologies (ICT) and advanced networking technologies with traditional infrastructures. The emerging developments in public utilities to be considered include the Smart Grid version of the electrical power network, the replacement of the telecommunications Intelligent Network with the transmission of sampled, quantised, digitised and encoded voice data over the Internet, and the replacement of privately owned computing devices by an assemblage of corporately owned processing power (cloud computing) at a centralised location, which can be accessed over the Internet.

Communication technologies

The essential networking protocols which make possible the transfer of data (with voice and video as well) over the Internet are known as Transfer Control Protocol (TCP) which monitors and controls data flow, and Internet Protocol (IP) which provides device addressing and data routing (Ancilotti, et al., 2013) over the network. These are the two essential components of what is known as the TCP/IP protocol suite which is at the heart of conceptual design of the Internet and which has proved enormously successful in enabling its almost unlimited growth in size and so its inherent scalability. These protocols are defined separately from, and so can operate over any Local Area or Wide Area Network (LAN or WAN) access technology or physical topology.

Communication networks based on the TCP/IP protocol suite are being increasingly recognised as having potential to transform public utilities. A general trend to be outlined in this paper is the use of intelligent processor-enabled devices in the utility to sense and self-regulate through peer-to-peer communications over the Internet. By “intelligence” is meant the capacity of integrated systems to respond to activation by providing advanced services, as well as to sense, predict and react to emerging situations and to take corrective action where necessary and without the necessary human intervention required by more centralised control.

System convergence

As noted above, electric power grids are most importantly required to provide uninterruptible power. Attempts to achieve this objective have, initially at least, used *ad hoc* conventional or legacy procedures by providing direct intervention to problem situations once they were recognised. This has been followed by centralised human monitoring using Supervisory Control and Data Acquisition (SCADA) technology, and now, using a communications network such as the Internet, methods are being researched to produce a largely self-regulating Smart Grid (Gao, et al., 2012). Here intelligence migrates from the central control to individual decentralised networked processor-enabled devices which can provide distributed intelligent peer-to-peer data necessary for self-regulation.

Telecommunications networks have traditionally been based on the Intelligent Network (IN) (Valdar, 2006, p 174) using circuit switching and limited client services (routing calls, establishing connections, as well as advanced features such as queuing, call forwarding and toll-free numbers). Endpoint devices in the IN, being simple 12-key pads to identify call requests, possess no capacity for intelligent behaviour. The circuit switched IN is currently, and however slowly, being replaced by the TCP/IP packet switching network, in fact by the Internet and using the Voice over Internet Protocol (VoIP) (Valdar, 2006, p. 169) to carry digitised voice data.

In cloud computing (Josyula, et al., 2012), individual users will no longer need to have direct access to their own expensive processing devices as processing power will, in the future at least, be available as yet another public utility. Access to processing power and software will be available through a TCP/IP network, typically the Internet, on demand.

In these examples of system convergence, a physical public utility is transformed into a cyber-physical (Mouftah & Melike, 2013, p. 633) system which carries the additional capacity of monitoring and efficient delivery of each particular service (structural convergence). In each public utility there can be observed an intelligence transfer from a central system component to distributed end-devices (functional convergence). The TCP/IP suite of networking protocols provides the required communication links and processor-based end-devices receive the communication required for their intelligent and predictive operation.

The Internet itself is also being transformed. From its initial function of providing global data flow between applications on computers, usually operating in client-server mode, the Internet is now being used to connect all kinds of processor-enabled machines (Neves & Rodrigues, 2010) and is being referred to by some (e.g. Asad, et al., 2013) as the Internet of Things (IoT). Simply stated, IoT refers to the interconnectivity of TCP/IP compliant core and peripheral devices providing all manner of applications and services on demand enabling new end-user experiences.

Ramu grid case study

Two possible industrial control technologies, Supervisory Control and Data Acquisition (SCADA) and Wireless Sensor Networks (WSN), which could be used on PNG Power's Ramu Grid (Figure 1) for monitoring purposes and which represent progressive decentralisation of control are discussed. In this electricity grid, as is typical of most power grids, the power source centres are located close to the raw material or other power generation energy sources which are in turn often located away from population and therefore load centres, thereby increasing the network geographical dispersal and creating the need for remote monitoring and control. Remote monitoring and control encompassing the generation, transmission and distribution segments of the network are necessary for enhanced power supply reliability. It is also noted that, as with many other national grids, this grid is aging with PNG Power having celebrated 50 years of operation in 2013.

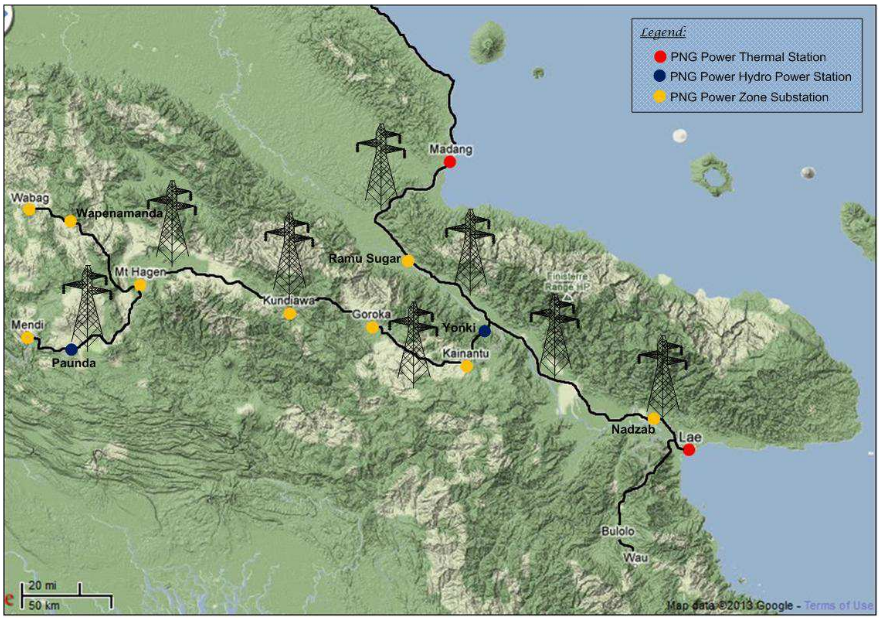

Figure 1: Satellite imagery of Ramu Grid coverage area from North-East to Central PNG and the Highlands

In the Ramu Grid, supplying load centres along the Ramu and Highlands Highways, the main power source is the hydro-electric power generating station situated at the Yonki dam on the upper reaches of the Ramu River (Figure 2). This station is a significant renewable energy resource of which there are potentially more in PNG situated as it is in the wet tropics with steeply dipping terrains allowing accumulation of gravitational energy. It is accessed along the eastern Highlands Highway, and possesses a total of 582MW expected generating capacity. In an ICT enabled structurally and functionally converged network, ICTs can offer the capability of even sensing whether or not 582 MW is within the current, medium or long term utility demands of the consumers. Such monitoring can pave the way for adequate network dimensioning to take place.

The Ramu 1 hydro-electric power plant consists of 5 by 15 MW turbines, with 2 more 9 MW turbines presently under construction. The grid also has a number of backup diesel generators such as the 2 by 4 MW generators in Madang, on standby in case of power outage in the main system. Other major load centres also have diesel powered generating stations to supplement the hydro-electric power supplied by Yonki station. The monitoring capabilities of ICTs can also coordinate or even switch between generators and turbines depending on the status of consumers demand.

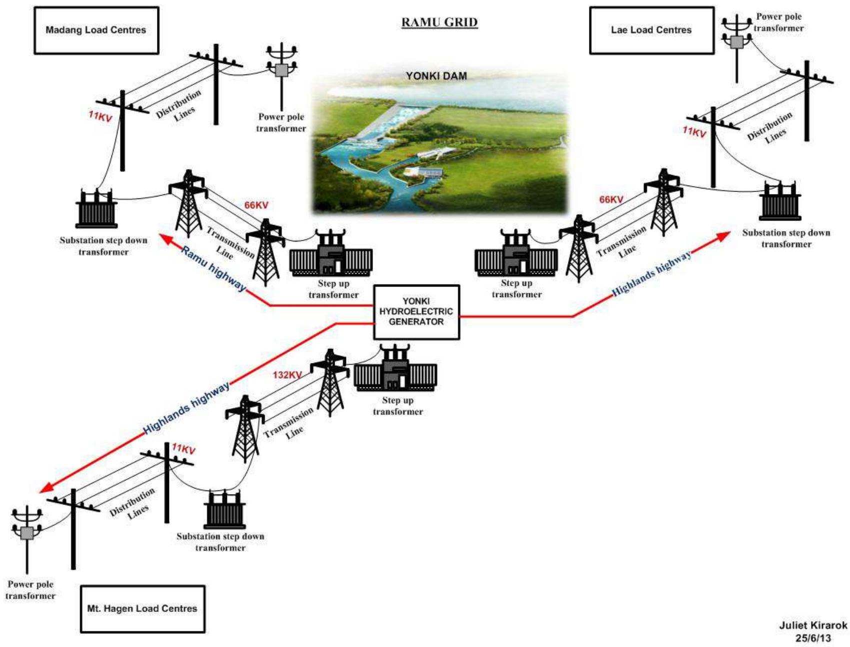

Figure 2: Schematic structural arrangement of equipment on Ramu Grid

From this station, separate transmission and distribution lines then traverse approximately 700 km along the National Highway to load centres at Lae in the east, Madang and Bogia in the central north-west, and then far into the Highlands to the west (Figure 2). Long distance transmission lines run at 132 KV and 66 KV, whilst shorter distribution lines run at 11 KV or 22 KV with voltage transformers and switching equipment located at the substations.

Step up transformers at the generating stations place power on transmission lines at high voltage and low current to minimise transmission energy loss. Step down transformers (132KV or 66 KV to 11 KV) are situated at distribution substations, with step down power pole transformers on distribution lines providing voltages (415/240V) suitable for industrial or domestic consumption.

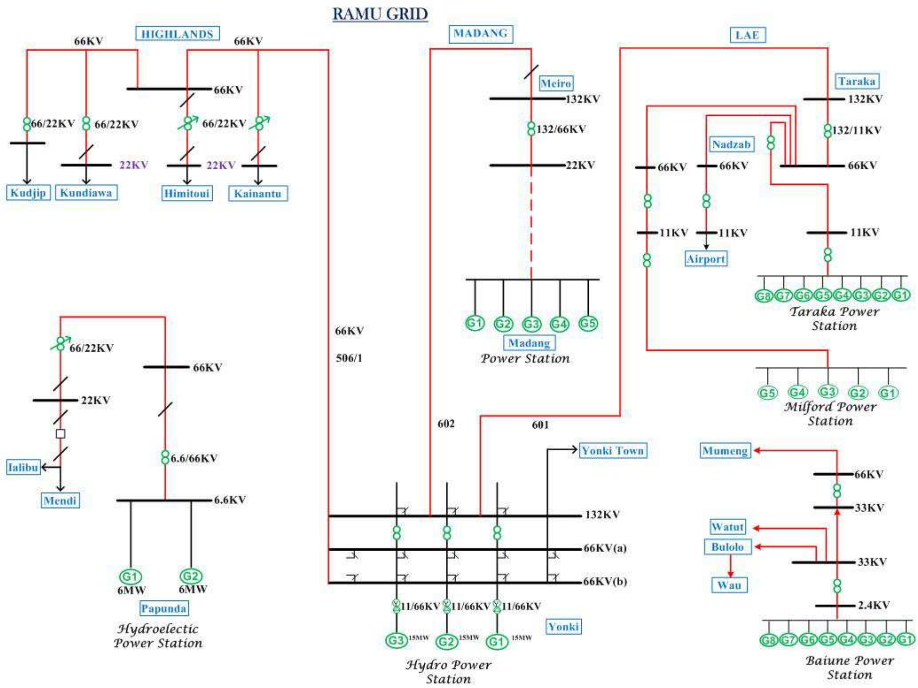

Figure 3: Simplified single line schematic diagram of Ramu Grid showing transmission lines (red) and bus lines (black)

The grid can also be represented in single line schematic (simplified representation of a 3 phase power system) format (Fig. 3, adapted from PNG Power Ltd. Ramu Transmission System Operating Diagram, SOD-255/2, 2008) showing overland high voltage (132 and 66 KV) transmission lines connecting to various substations prior to distribution at Lae, Madang and Highland areas. Lower power backup diesel generating stations are also shown at Lae (Taraka, Milford and Baiune power stations), Madang and Highlands.

Distribution sub-stations

Distribution substations, where high voltage transmission lines connect to lower voltage distribution lines to feed local load centres, are critical monitoring and control points in an electricity grid. The Meiro substation located at the entry to the Madang load centre is a typical substation shown as a logical diagram (Figure 4) and a physical diagram (Figure 5) (drawn for this paper from personal observation). Critical safety and control devices essential for electronic monitoring are located.

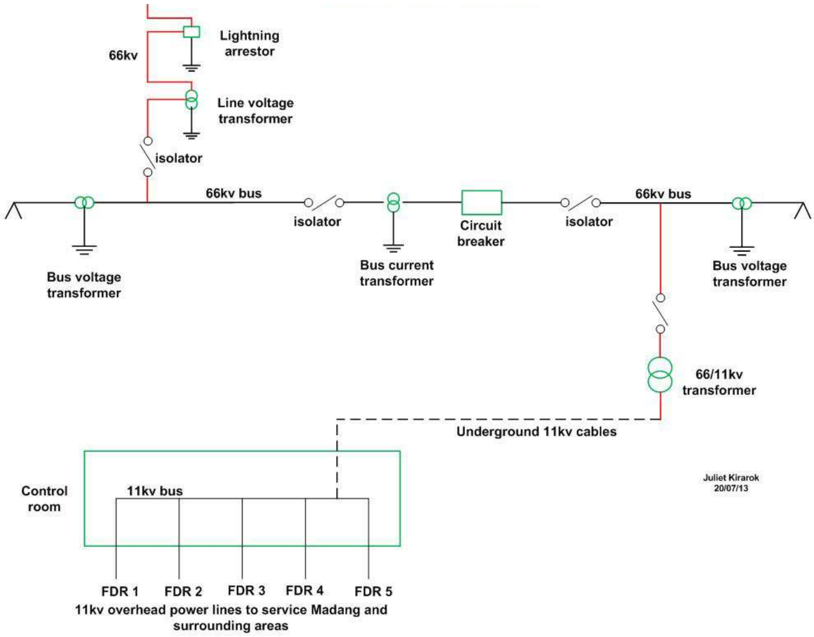

Figure 4: Single Line schematic diagram for the Meiro Distribution Sub-station, Madang

Substations contain electrical elements such as circuit breakers, transformers, voltage and current transformers for measurement, capacitors for phase control, bus bars (black) for distribution to feeder lines, and conductors (red) using standardized schematic symbols. Together with the generating stations, the substations contain critical measuring equipment for network monitoring. Power flows in three phases shown as separate lines in the physical diagram (Figure 5). Each phase has its own circuit breakers, measuring instruments and transformer elements.

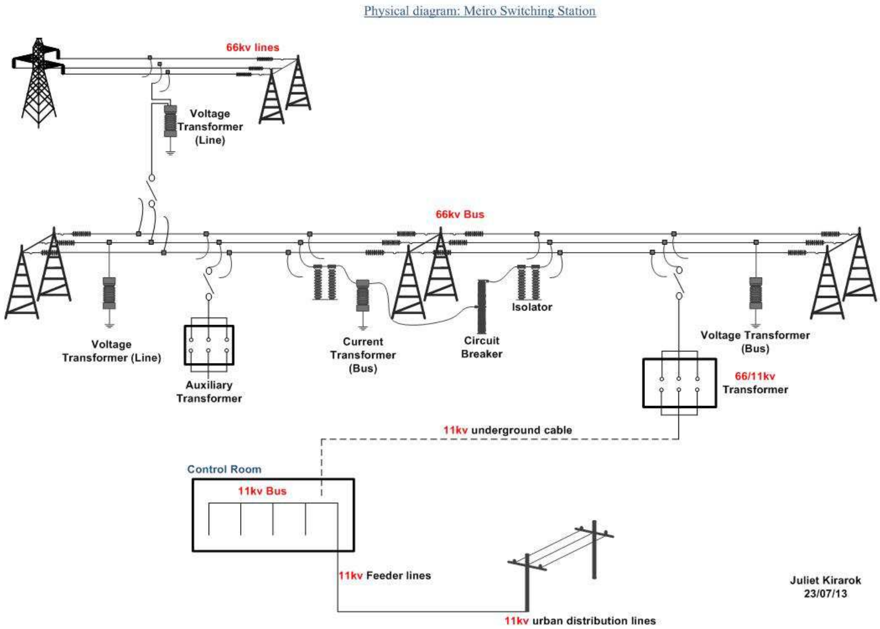

Figure 5: Three phase physical diagram for Meiro Distribution Substation, Madang

Grid maintenance

The Ramu Grid distribution lines follow the National Highway for approximately 700km as previously noted linking various load centres and traversing long stretches of uninhabited terrain (Figure 1). These large distances make fault trouble shooting difficult and introduce unacceptable time delays in power outage recovery. As well, information is needed by grid operators to ensure optimal use of the valuable public assets installed on these networks. Automated error detection and recovery systems such as SCADA and WSN to be discussed here, using ICT networking technologies are available to enhance power delivery and enable rapid detection and recovery.

Supervisory control and data acquisition (SCADA)

SCADA, an Industrial Control System (ICS), is a network of intelligent devices, which uses sensors reading system monitoring equipment at remote mission critical system control centres (Figure 6) such as generating stations and transmission line substations to collect real-time data related to the operation of essential equipment in the system (Ancillotti et al., 2013, p.1667).

Data from sensor devices, typically indicating circuit breaker status, or current or voltage levels, attached to measuring devices on managed sections of the grid are received by Remote Telemetry Units (RTUs). To these are attached control relays which contain the logic to provide the necessary local response to alerts received from sensors of possible unsafe or other undesirable situations developing.

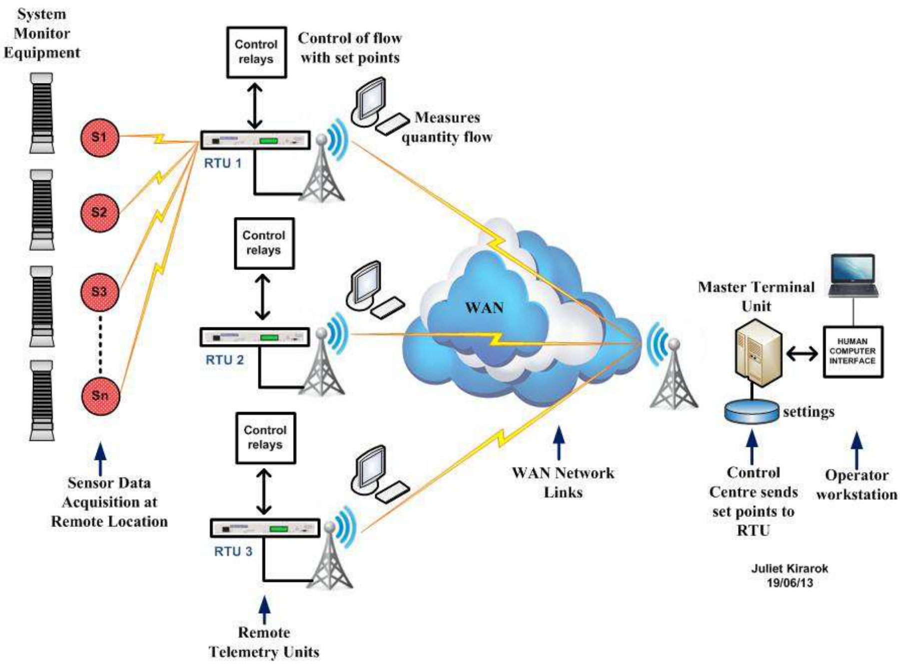

Figure 6: SCADA system components coordinating a network of error detecting intelligent devices using a point to multipoint configuration

Multiple RTUs can then use wireless or other WAN data networks (fiber optic, cellular, power line communication) to report data from their local sensors to a centralized SCADA master control unit at a Central Monitoring Station (CMS) which runs software to provide a human-computer network interface for centralised control purposes. Reported data will typically be of significant changes in operating conditions or data falling outside of safe ranges, defined as set points.

A comprehensive view of the whole network operation can be displayed on a flow chart type graphical representation of the real utility network with real-time measured readings being displayed at critical points on the graphic. Safe ranges and trip values of critical readings are provided from software available on the CMSs.

While SCADA systems control present day power grids, they rely on human operators and limited sensing (Melike & Mouftah, 2011). With this level of sensing and only one way communication they have limited monitoring and self-regulating capabilities. However, in complex real-time systems such as power grids, decisions and responses are often needed rapidly. To achieve this, human operators need to be replaced by decision and control software to provide immediate and appropriate response to critical situations. Next generation grids, Smart Grids, will need to be more autonomous with actor devices complementing sensors to provide responses in real-time.

Wireless sensor and actor networks

Wireless Multimedia Sensor and Actor Networks (WMSAN) have been proposed for the next generation power grids (Melike & Mouftah, 2011) known as Smart Grids. These networks will consist of large numbers (thousands) of low cost unattended sensing devices requiring minimum human intervention and located on power lines (Figure 7) and networked via wireless links.

Whereas SCADA devices are placed at mission critical points in a network, these sensing devices can be positioned down to the level of individual power line spans enabling an unprecedented high level of error detection and location specificity. Balancing the sensor network there is an equally complex actor network (shown only as a cloud on the right in Figure 7) to activate devices required to make appropriate responses to emerging situations. Actor networks respond to distributed decision and control algorithms to provide services such as load balancing, power switching and grid isolating (Melike & Mouftah, 2011).

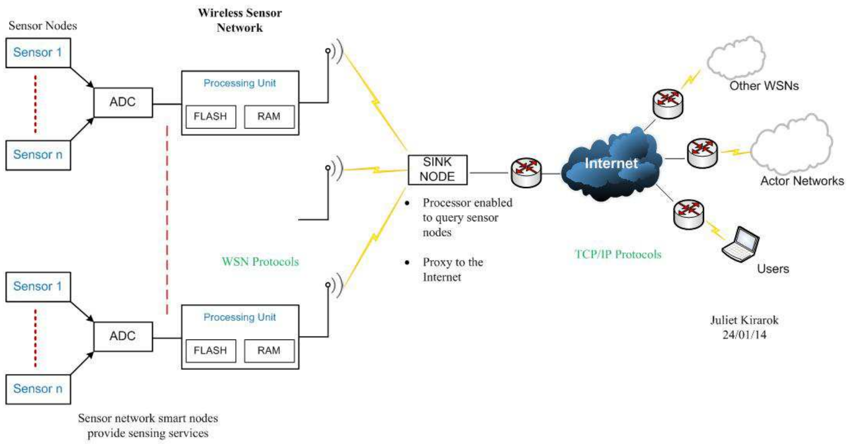

Figure 7: Wireless Sensor and Actor Network to enable the electricity grid to function as what is now known as a Smart Grid

The sensor-actor wireless network is the essential component of the Smart Grid. Among its special advantages are the effective sensing to include cost and revenue considerations and benefits to ensure paying customers are served efficiently. Ultimately economic and opportunity costs of generation, transmission and distribution can be minimized to improve the financial health of a power grid and at the same time enhance the service experience of consumers. However, Smart Grids also pose another advantage relating to the contribution in the fight against Green House Gas (GHG) emissions.

The integration of sensing devices through ICTs consolidated together with Smart Grids can lead to proper coordination of power generation turbines and generators which would be working and operational only on demand. This means turbines and generators are working less when demand is not at peak and reducing GHG as opposed to working at optimum levels irrespective of demand levels.

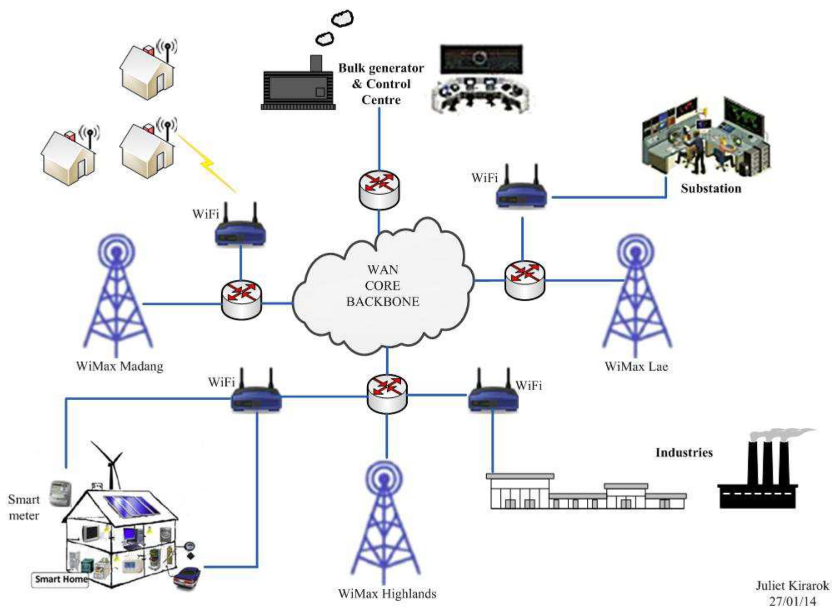

Figure 8: Schematic diagram showing a hypothetical wireless sensor and actor network for the Ramu grid

The implementation of such a wireless network (Figure 8, adapted from Figure 5, Ancillotti et al., 2013) will require a WAN core backbone network to which WiMAX (Worldwide Interoperability for microwave Access) access can be had from major load centres (Lae, Madang, and various Highland centres), energy generating stations, various sub-stations and control centres over distances of 50-100 km. For shorter distance access can be had through WiFi (Wireless Fidelity) networks. The network enables two-way communication. End-users can make intelligent and economical adjustments to their energy usage as represented by the “Smart Home”. Energy generated locally (solar or wind power) can be fed back into the system thereby reducing energy bills. A future prospect for the Smart Grid is the large scale use of HPEV (Hybrid Powered Electric Vehicles), plugged into the electricity grid when not in use, to store surplus energy during periods of low demand, or to help supply energy during periods of peak demand.

Telecommunications over IP networks

As previously noted, the circuit switched telecommunications Intelligent Network (IN) will eventually be fully replaced by the TCP/IP packet switching network, in fact by the Internet and using the Voice over Internet Protocol (VoIP) (Valdar, 2006, p. 169) to carry digitised voice data. Processor-based end-devices carrying software applications such as IP based devices (phones, personal digital assistants (PDA)) replace the 12-key pads, thereby producing intelligent end-devices providing services only limited by the imagination of software developers, and "best effort" (Gao et al., 2012) delivery of the voice data over the Internet (Figure 9).

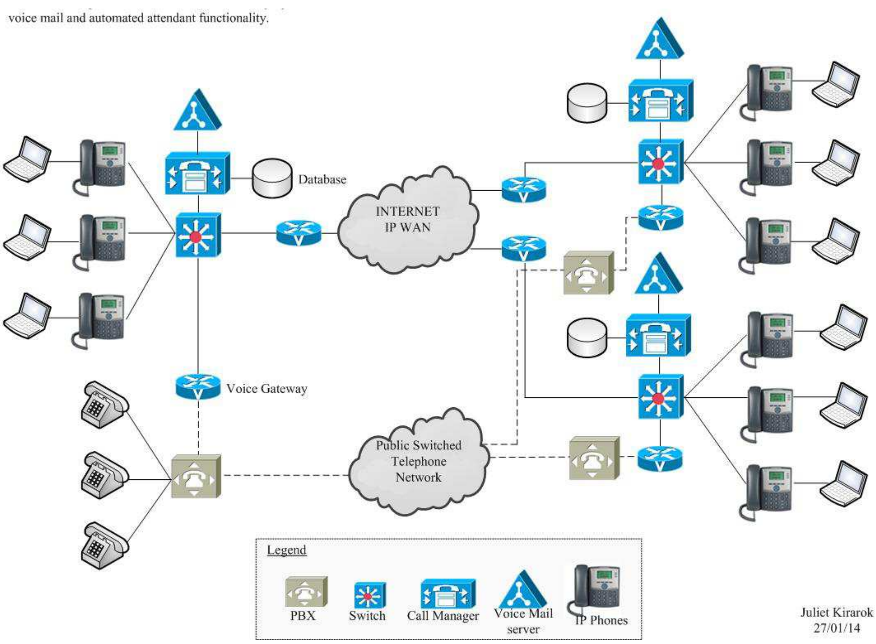

Figure 9: Logical diagram showing the IP based end-devices with Internet IP WAN connectivity as a telecommunication network alternative to the PSTN

The IP WAN carrying voice data is typically offered as a preferred alternative to the Public Switched Telephone Network (Figure 9). Digitised voice packets from IP phones are initially directed to a software-based call processing system, the Call Manager (CM), running on a server which has database access to store tables linking phone numbers to IP addresses. The CM replaces the Private Branch Exchange (PBX) used in the PSTN in an IP telephony environment. Its functions to control IP phones, make call forwarding decisions, forward data to a voice messaging server for voice mail and the services of an automatic attendant, and offer such advanced features as conference calling and call forwarding. It can also, where necessary, such as in the event of congestion on the IP WAN network, direct calls through the PSTN. The CM, therefore, can be seen to enhance the intelligence of the end-devices, an intelligence transfer noted elsewhere in this paper.

It is interesting to note, however, that successful voice transmission requires an increase in intelligence of the network in order to provide sufficient quality of Service (QoS). Thus, the network must be able to identify digitised voice packets as such to give them transmission priority over other data packets thereby avoiding unacceptable delays or variable delays (jitter) in voice transmission.

Processing power over IP networks

Again as previously noted, a third and emerging public utility, known as cloud computing (Josyula, et al., 2012), will take advantage of the Internet. It will enable individual users to have direct access to computer processing power without needing their own expensive devices and software (Figure 10). Access to these resources will be available through a TCP/IP network, typically the Internet, and on demand, as is the case in an electricity network.

Clients anywhere and at any time using cloud computing interface software such as a Web-based browser and one of a variety of inexpensive terminals (Figure 10) will have secure access to computing facilities through one of a number of possibly peered processing centres. Each data centre will have large scale processing power supported by on site power generators, Uninterruptible Power Supplies (UPS), power distribution units and cooling units. The processing data centres (Figure 10) are shown as icons within the cloud as part of the previously described IoT. Linking lines suggest peering which would enable high demands to be transferred to other sites, much as might occur within an electricity grid.

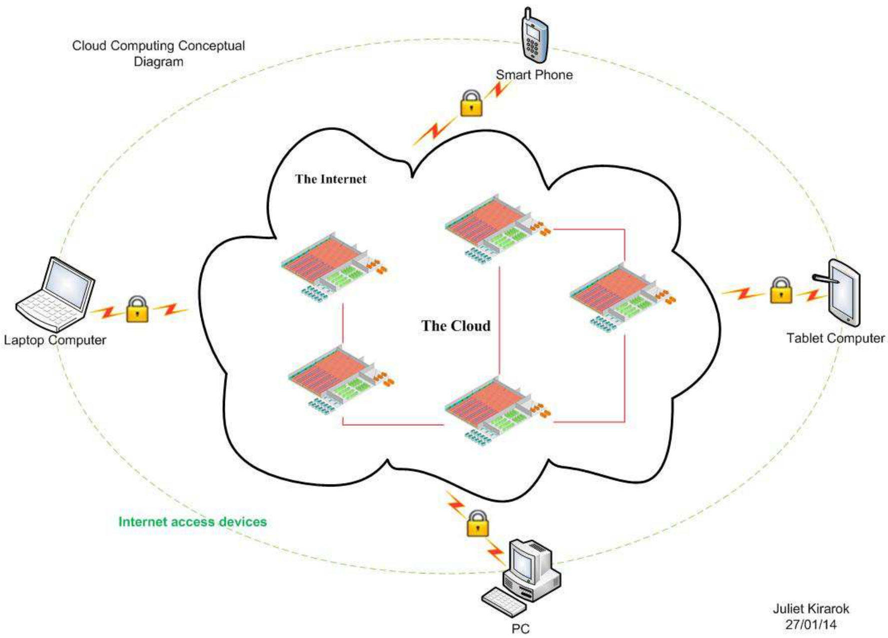

Figure 10: Computer processing data centres, peering where desired within the cloud, making secure processing power available as a public utility

Among the special services which might be provided by the cloud (Josyula, et al., 2012, p 12) are access to application software (SAAS: Software as a Service) managed by the client's browser, a platform for running applications on server operating systems (PAAS: Platform as a Service), and computer infrastructure (IAAS: Infrastructure as a Service) where the client has remote but full control over allocated hardware.

In terms of distribution of intelligence, in a manner similar to the IP phone network, intelligence is at the end devices with the TCP/IP network providing best effort delivery. However the asymmetric nature of the intelligence distributed as it is over a client-server model. Client end devices running Web browsers need have minimal processing intelligence which now accumulates in the data centres within the cloud, the server end devices.

Conclusion

This paper has discussed the development of system convergence in public utilities as they are transformed from physical systems to cyber-physical systems using processor-based end-devices and networks based on Internet protocols. In this convergence, common structural and functional characteristic can be observed in the various network elements. The structural convergence is the common integration of the TCP/IP network into the physical system, whilst the functional convergence is the migration from core to intelligent periphery network elements.

One such utility discussed in detail is the electricity power grid with the Ramu Grid (PNG Power) providing a local example of the electricity grids in PNG. This grid is the most extensive and therefore most eligible for the monitoring and self-regulation possible with cyber-physical systems to ensure efficient and reliable electrical power delivery. A centrally administered remote industrial control systems (SCADA) now being implemented on this grid has been described as a means to provide improved energy delivery and reliability. Beyond the human-computer centralised control of SCADA networks, Wireless Sensor and Actor Networks are proposed to use advanced ICT communication methods to transfer intelligence from a central monitor to critical system devices to enable sensing and self-regulation. In this Smart Grid, intelligence is spread throughout the grid rather than located in a central control centre.

In a similar way, ICT in telecommunications networks has been shown to spread intelligence from the core network (Intelligent Network) to peripheral software and processor-enabled end-devices such as VoIP phones or related personal devices.

Cloud computing is yet another example which is understood in terms of using ICT technology to decentralise what is destined to become a public utility. Here the Internet is used to access processing power on demand from a public utility provider which makes large scale computer processing power publicly available.

The transformative effect on the Internet is that it is now being used to connect all kinds of processor-enabled machines and is being referred to by some as the Internet of Things (IoT).

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Glossary

CMS	Central Monitoring Station
CM	Call Manager
GHG	Green House Gas
HCI	Human Computer Interface
IAAS	Infrastructure as a Service
ICT	Information Communications Technology
ICS	Industrial Control System
IN	Intelligent Network
IoT	Internet of Things
IP	Internet Protocol
KV	Kilo Volt
KVA	Kilo Volt Amp
LAN	Local Area Network
MW	MegaWatt
PAAS	Platform as a Service
PBX	Private Branch Exchange
PDA	Personal Digital Assistant
PLSM	Power Line Sensor Module
PLSAN	Power Line Sensor and Actor Network
PSTN	Public Switched Telephone Network
RTU	Remote Telemetry Unit
SAAS	Software as a Service
SCADA	Supervisory Control and Data Acquisition
SG	Smart Grid
TCP	Transport Control Protocol
TCP/IP	Internet Protocol Suite
UPS	Uninterruptible Power Supply
VoIP	Voice over IP
WAN	Wide Area Network
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WSN	Wireless Sensor Network
WMSAN	Wireless Multimedia Sensor and Actor Network