OpenWay Riva™ Adaptive Communications Technology

Field Trial Summary: Large Asian City, Fall, 2014

CONTENTS

WHITE PAPER

ABOUT THIS DOCUMENT

In 2014, Itron introduced its next generation field communications technology, called Adaptive Communications Technology (ACT), an integral part of our OpenWay Riva™ solution. Starting the same year, Itron and a number of utilities around the world undertook field trials of ACT to evaluate the ability of the solution to address different, utility- or environment-specific connectivity and performance challenges, often distinct to the host utility.

This document captures the experience and results of one key trial. Companion documents will provide similar insights into the experiences and results of similar trials with other host utilities. In all cases, a general overview of ACT will be shared in an introductory section. Additionally, the objectives of each host utility and the methods employed to evaluate ACT will be shared in order to place the reported results in proper context.

In all cases, the specific identify of the utility and the exact location of the trial has been abstracted, per the wishes of the trial hosts.

ADAPTIVE COMMUNICATIONS TECHNOLOGY OVERVIEW

Itron has drawn on its extensive experience connecting more than 120 million devices to field area networks around the world to design differentiating last mile communications technology suitable to address both the challenges of smart metering business cases today and emerging smart grid and smart city opportunities in the most cost-effective manner. Our design objectives in developing this technology were as follows:

1. Provide cost effective, >99% network coverage in all environments with a single technology
2. Ensure >99% node availability in any environment
3. Create a common network infrastructure for both electric and battery powered devices
4. Support applications and use cases beyond smart metering
5. Leverage global IT networking standards to provide;
   - IP-based network mitigation tools (Ping, Traceroute, etc.)
   - Long term solution evolution
   - Open Eco system of partner devices and applications
6. Enable our customers to leverage common, scalable, and multi-service networking technologies, independently of the physical field communications

The result of our efforts is OpenWay Riva Adaptive Communications Technology (ACT.)

ACT: MULTIPLE MEDIA, MANY MODULATIONS, ONE SELF-OPTIMIZED NETWORK

ACT uses both RF and PLC links within a multi-hop IPv6 mesh to route messages and data between field devices and enterprise systems and to facilitate peer-to-peer communications within the network itself. The technology also includes Wi-Fi capability, which is currently used for local field access and programming. ACT features embedded intelligence that enables each device in the network to choose the best communication media (RF or PLC) and modulation scheme at any given moment to create network links with the best possible data rates (up to 600 kbps.) This media and modulation selection is done automatically and dynamically, in real-time, by the devices themselves without any need for pre-programing or path hard-coding. Rather, routing is managed by standardized IETF routing protocols which are independent of the physical link.

Specifically, the following modulation options are available to each node in the network in order to dynamically "gear shift" to maximize data rates when conditions are favorable, or "gear shift" to achieve longer range or more stable connectivity when interference and other environmental challenges are introduced:

» Adaptive RF Data Rates (Modulations)
- 600 kbps (802.15.4g OFDM option 3 MCS6)
- 200 kbps (802.15.4g OFDM option 3 MCS3)
- 150 kbps (½ FEC 802.15.4g FSK)
- 12.5 kbps (802.15.4g OQPSK DSSS RM0)

» Adaptive PLC Data Rates (Modulations)
- 200 kbps (D8PSK)
- 165 kbps (DQPSK)
- 100 kbps (DBPSK)
- 34 kbps (ROBO)

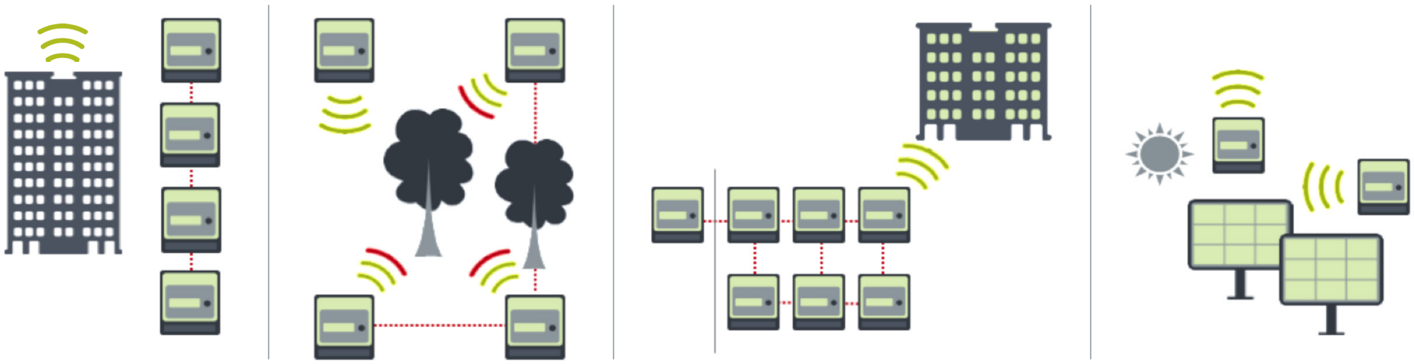
ACT not only provides assured connectivity at the highest possible speed, it also enables a network architecture that provides additional benefits compared to traditional single-media networks:

» **Simplification:** By combining RF and PLC communications on every device, the utility does not have to choose between these technologies for specific areas of their deployment. Network planning, network deployment, and network maintenance are greatly simplified.

» **Lower Cost Network Infrastructure:** With both PLC and RF communications, and Cisco Field Area Router (called "Connected Grid Routers" or "CGR") capable of routing up to 10,000 endpoints as maximum (6K mains powered + 4K battery powered), the need for a device at every distribution transformer is eliminated. In addition, RF links can mesh together electrically disconnected PLC clusters. This substantially reduces the total number of backhaul takeout points, resulting in significantly lower device counts and lower backhaul costs, and reduced network maintenance requirements.

» **Improved Reliability:** The RF medium allows for alternative communications paths when the Field Area Router or its backhaul link fails. In a traditional PLC-only/Collector deployment, the meters cannot communicate if the Collector or backhaul link fails. With Adaptive Communications Technology, the meters can route their traffic to a neighboring Field Area Router using a combination of RF and PLC links to maintain network communications during these failure events.

MEETING CONNECTIVITY CHALLENGES



High-Rise Buildings *Changing RF Conditions* *Underground Meter Vaults* *Low-Density Environments*

Highly urbanized and dense service environments, high rises, heavy concrete infrastructure, and below-ground device locations present formidable challenges to single-medium field area communications. Similarly, areas with low device density can pose a challenge for traditional mesh networks and for PLC communications.

In a mesh-only configuration it would be necessary to engineer site specific mitigations (range extenders, remote/external antennas, etc.), thus raising the cost of equipment for those areas. Itron's long-range ACT/RF modulation more than doubles the effective range of the radios by dynamically lowering the bandwidth where and when necessary. This enables the ACT solution to more cost-effectively serve lower density rural areas where endpoint population is small and dispersed.

LATENCY

Message latency in this IPv6 network is as rapid as 20 ms with an average of 150 ms per hop. The mesh network operates as a shared-medium network and dynamically switches the mode of operation from RF to PLC. Therefore, the per-hop latency is not deterministic, but rather a statistical value that depends on node density, traffic load, quality of service, and modes of operation used at each hop to communicate with the neighbor nodes.

Downstream commands/messages from the enterprise systems to an edge device depend on the number of hops between the targeted edge device and the Field Area Router and typically average between 1.1 seconds for a one-device hop to 1.7 seconds for a 4–device hop. With regard to multicasting, commands/messages can be multi-casted to small and large groups (such as 100,000) or all endpoints, and will typically reach all targets endpoints within 2 seconds.

Upstream alerts/messages from an edge device to an enterprise system are also dependent on the number of hops from the Field Area Router to the edge device and have the same range of times as the downstream traffic: 1.1 to 1.7 seconds.

QUALITY OF SERVICE (QOS)

The scalable IETF Differentiated Services (DiffServ) from Cisco delivers IP quality of service (QoS) that is needed when integrating multiple classes of traffic over the IP network. This is an enterprise standards based implementation by Itron. The IETF DiffServ implementation is supported by four priority queues in each node of the network to provide a comprehensive QoS capability.

Both endpoints and backend applications use the DSCP field in the IP header to mark packets for low, normal, medium or high-priority treatment based on required performance. The communication nodes then queue the individual packets based on the DSCP marking. The packets held in the queues are released in a strict priority order within the mesh nodes in order to keep the latency requirements of higher priority applications.

As this IP-level, QoS prioritization only becomes active in times of network congestion, it is much more efficient and flexible than dedicating a specific physical channels statically or dedicated network hardware to a certain application, as is the current standard in many proprietary network solutions on the market.

No intermediate storage of the request or response occurs in the network itself. The Field Area Router (and all other network nodes along the path to the targeted endpoint) routes the traffic in real-time to its destination.

This ensures that no temporarily stored data will be lost in case of a device failure. Instead, the network will either route the traffic around the failure point in a larger cell, or the application protocol will automatically resend the data.

SUMMARY OF ACT CHARACTERISTICS

The following tables summarizes ACT's Field Area Network characteristics and also notes that both 870-876 Mhz and 902 – 928Mhz RF options (or subsets thereof) exist.

RADIO FREQUENCY (RF) CHARACTERISTICS

Characteristic	RF 870-876 MHz	RF 902-928MHz
IEEE Standard	IEEE 802.15.4g PHY layer IEEE 802.15.4e MAC layer format	IEEE 802.15.4g PHY layer IEEE 802.15.4e MAC layer format
Frequency and Channelization	870-876 MHz 200 kHz channels, between 14 and 27 channels *(Sub-channelization possible, e.g. 870-873 MHz)* *(according to ER-GSM coexistence reqs./exemptions)* *(EN303204 under discussion at EU)*	902-928 MHz ISM band 400 kHz channels, up to 64 channels *(Sub-channelization possible, e.g. 915-928 MHz)* *(FCC part 15 regulation)*
Adaptive Modulation Scheme	802.15.4g OFDM option 4 802.15.4g OQPSK DSSS ("Long Range") 802.15.4g FSK	802.15.4g OFDM option 3 802.15.4g OQPSK DSSS ("Long Range") 802.15.4g FSK
Data Rate	Adaptive RF Data Rates • 300 kbps (802.15.4g OFDM option 4 MCS6)* • 200 kbps (802.15.4g OFDM option 4 MCS5) • 150 kbps (½ FEC 802.15.4g FSK) • 12.5 kbps (802.15.4g OQPSK DSSS RM0) **Max RF bit rate limited to comply with channel width specified in EN 303 204*	Adaptive RF Data Rates • 600 kbps (802.15.4g OFDM option 3 MCS6) • 200 kbps (802.15.4g OFDM option 3 MCS3) • 150 kbps (½ FEC 802.15.4g FSK) • 12.5 kbps (802.15.4g OQPSK DSSS RM0
RF Conducted Power	29 dBm	30 dBm (maximum)
Maximum Transmit Power	25 dBm ERP (maximum)	26 dBm
RF Receive Sensitivity (10% PER)	Long Range 12.5 kbps: -122 dBm FSK 150 kbps: -106 dBm OFDM 200 kbps: -111 dBm OFDM 300 kbps: -108 dBm	Long Range 6.25 kbps: -122 dBm FSK 150 kbps: -106 dBm OFDM 200 kbps: -112 dBm OFDM 600 kbps: -102 dBm
RF Link Budget	Long Range 12.5 kbps: 149 dB FSK 150 kbps: 133 dB OFDM 200 kbps: 131 dB OFDM 300 kbps: 128 dB	Long Range 6.25 kbps: 150 dB FSK 150 kbps: 135 dB OFDM 200 kbps: 131 dB OFDM 600 kbps: 121 dB
Max. Transmission Time (ms)	400 ms for each 10 seconds (according to EN 303 204)	400 ms for each 10 seconds
Duty Cycle (%)	2.5% for end devices, 10% for router	4% for end devices, 4% for router
Encryption	AES 128-bit, IEEE 802.1x	AES 128-bit, IEEE 802.1x

POWER LINE CARRIER (PLC) CHARACTERISTICS

Characteristic	PLC (FCC above Cenelec)
IEEE Standard	IEEE 1901.2
Frequency and Channelization	FCC above CENELEC *(OFDM tone-masking possible)* *(Frequency notching possible)*
Adaptive Modulation	D8PSK DQPSK DBPSK ROBO
Data Rate	200 kbps (D8PSK) 165 kbps (DQPSK) 100 kbps (DBPSK) 34 kbps (ROBO)
Encryption	AES 128-bit, IEEE 802.1x

FIELD TRIAL OVERVIEW

Itron and a utility serving a large Southeast Asian city conducted a field communications trial of ACT in order to determine whether the combination of RF and PLC in a single communications mesh would improve the following:

» Inter-building connectivity in large high rise building complexes
» Meter to router (or "takeout point") ratios (increasing the ability to address more meters with one field area router)
» Connectivity to remote, hard to reach meters, including 'missing link' and 'partial deployment' cases
» Overall network connectivity, stability and robustness
» Deployment and mitigation effort requirements

During the trial, a total of 170 Itron ACT-equipped meters and three Field Area Routers were deployed at different, mutually-selected locations throughout the utility's service territory. Meter density was varied at each location and, in all cases, complete saturation of ACT-enabled devices was avoided in order to simulate hard to reach and partial deployment use cases. Deployments were as follows:

» 103 meters in a high-rise residential and shopping mall site with estimated 1,600 meters total
» 42 meters in a low-rise tenement building with an estimated 2,000 meters total
» 25 meters in a more remote village site with estimated 300 meters total.

The trial demonstrated that both PLC and RF links were necessary to effectively address all deployment cases and to achieve near 100%, reliable connectivity. Key outcomes observed in the trial included the following:

» PLC links were established where RF links were not available (the missing link use case)
» Long distance PLC links were created in all three sites, with sufficient throughput to support smart metering and smart grid use cases
» Building-to-building connectivity was established with no mitigation required using both media (RF and PLC)
» Long range RF links were used to establish building-to-building connectivity
» A large reduction in field mitigation efforts was extrapolated due to the adaptability of the network via the two media, and the multiple modulations.
» Sparse deployment connectivity was not an issue
» High expected meter to Field Area Router ratios
  - Site 1 High Rise – 1:1,600+
  - Site 2 Tenement – 1:3,000+
  - Site 3 Village – 1:300+

A five-day Acceptance Test was completed with a 99.93% averaged load profile read rate over all sites.The trial demonstrated the ability of ACT to provide reliable connectivity in diverse, practical deployment situations in unique local conditions and to provide a stable field area network with minimal mitigation.

TRIAL PARAMETERS

Itron OpenWay Riva meters, equipped with the ACT technology were installed in all three sites in a sparse deployment, with meters distributed throughout the population. The meters were installed on meter boards alongside existing billing meters to most accurately reflect real-world deployment conditions.

The primary objective of the testing was to achieve connectivity within each site, and following a period of connectivity testing and measurement, to demonstrate that a read-rate of >98% could be demonstrated consistently over a period of 5 days.

During the setup and following the five-day read-rate testing, a number of additional use cases were also tested at the high-rise building complex site to demonstrate:

» Building-to-building connectivity via long range RF links
» PLC links where RF links were not possible
» Links from meters in substations via PLC links
» A range of inter-floor links

ACT CONFIGURATION

RF:

» Output power (average): 29-29.5 dBm
» Best FSK link sensitivity:- 103 dBm. Total Isotropic Sensitivity (TIS): -98 dBm
» Best LR Link sensitivity: -114 dBm. Total Isotropic sensitivity: -109 dBm
» Antenna efficiency: -2 dB. Antenna Gain 2.9 dBi (including directivity and efficiency)
» Frequency band: 920-925Mhz (11 Channels; 400kHz Spacing)

PLC:

» Output Level (Maximum): 123 dBμV
» Output Level (Average on 2 Ohm load): 114 dBμV
» Best D8PSK sensitivity: 44 dBμV
» Best ROBO sensitivity: 30 dBμV
» Frequency Band: 154.7-487.5 kHz

Cisco Connected Grid Router with Itron ACT PIM Module:

» RF Transmit Power: 28 dBm
» Frequency band: 920-925Mhz (11 Channels; 400kHz Spacing)
» Antenna Gain: +5dBi Omni directional

MODULATION TYPES AND DATA RATES

RF:

» FSK – 75Kbps
» LR – 6.25Kbps

PLC:

» 8-PSK – Up to 200Kbps
» Q-PSK- Up to 150Kbps
» B-PSK – Up to 75Kbps
» ROBO – Up to 23Kbps

NOTE: As this was an early trial of ACT, only a subset of the complete set of RF modulations were supported by the radio. The higher OFDM modulations have been added subsequently.

SELECTED LOCATIONS

ACT-enabled meters were deployed in the following three locations in order to evaluation the technology in very distinct sets of conditions:

1. A high rise complex with a dense total meter population exceeding 1,800 meters within two residential towers and a shopping mall. A total of 103 Meters were deployed throughout the testing site.

2. A low-rise tenement site with a medium meter density exceeding 2,000 meters within the testing area. 42 meters were deployed in the testing site.

3. A village site with a medium-to-low meter density exceeding 300 meters within the testing area. 25 meters were deployed in the testing site.

METER CONFIGURATION AND READING SCHEDULE

The requested data from the meters was chosen to closely match the host utility's expected production configuration, including load profile reads, events, and register data. The amount of data requested during the trial exceeded that of expected meter configurations in an AMI deployment scenario, but was useful to identify any constraints or limitations in network performance. The ACT meters were therefore configured with four channels of 15-minute load profile data. This represents approximately twice the volume of data expected in a typical production scenario, therefore stressing the network in an appropriate manner and replicating an environment containing many more meters.

The interrogation methodology of the host utility is to allow meters multiple chances per day to provide load profile, event, and register data. The system used to drive the ACT trial was therefore configured to interrogate all meters, multiple times throughout the day. The read window for all groups was configured to a two-hour period. This was useful for determining success read rate at different times of the day.

Read rate figures quoted for each of the three sites are for a two-week period. This two-week period includes the five day performance test period of September 23-26 and September 29 (five consecutive business days).

TEST RESULTS: HIGH-RISE COMPLEX

The high-rise complex was selected as the trial's highest priority site for its meter population density, shopping mall on the lower floors and expected challenges to RF-only mesh networks.

A total of 103 OpenWay ACT RIVA meters were deployed throughout both residential towers and to all meter rooms within the shopping mall. Distribution was spread evenly across floors, phases and meter room verticals. A single Field Area Router was deployed in the ground floor substation, highlighted in blue, for the majority of the test.

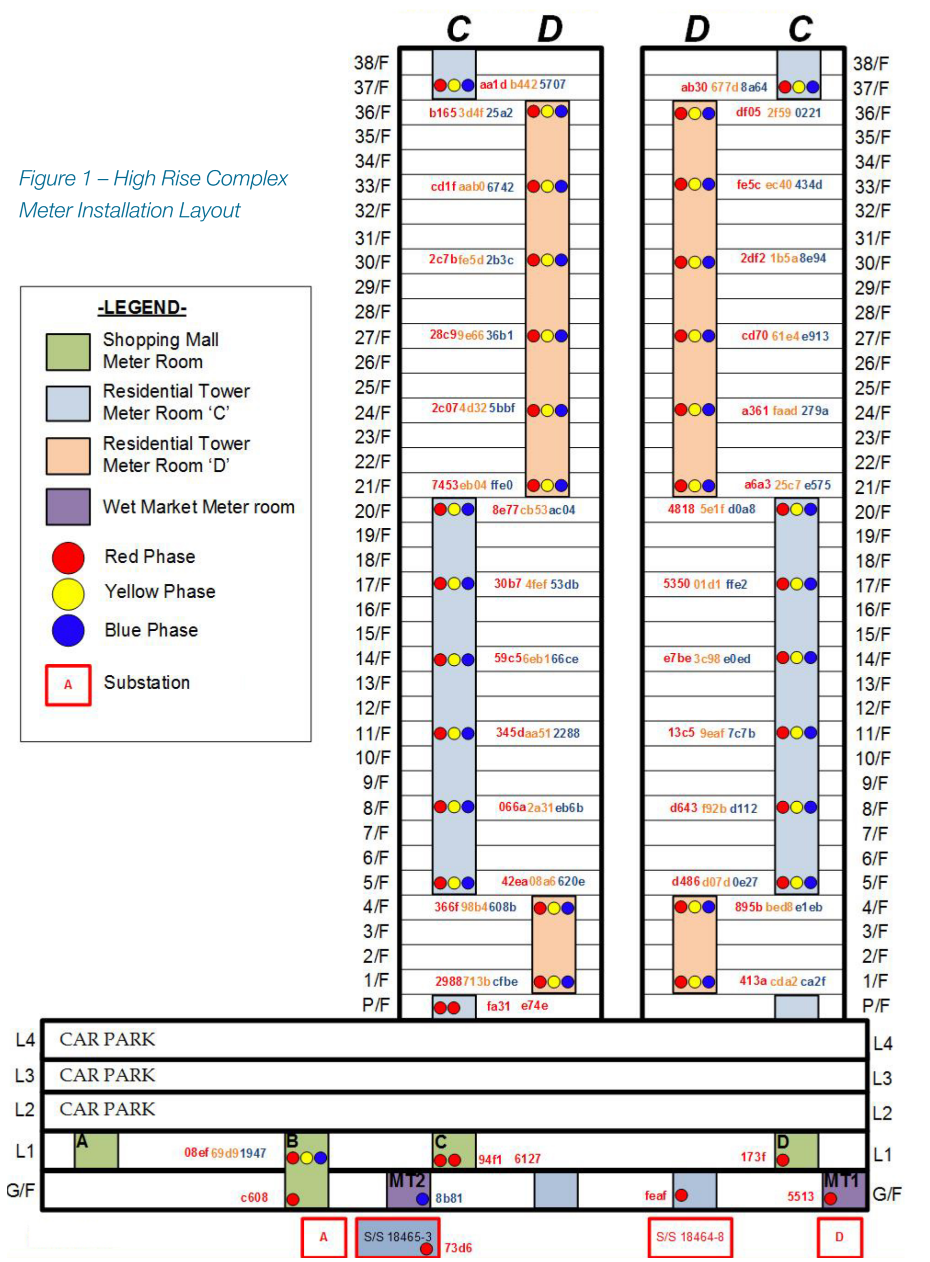
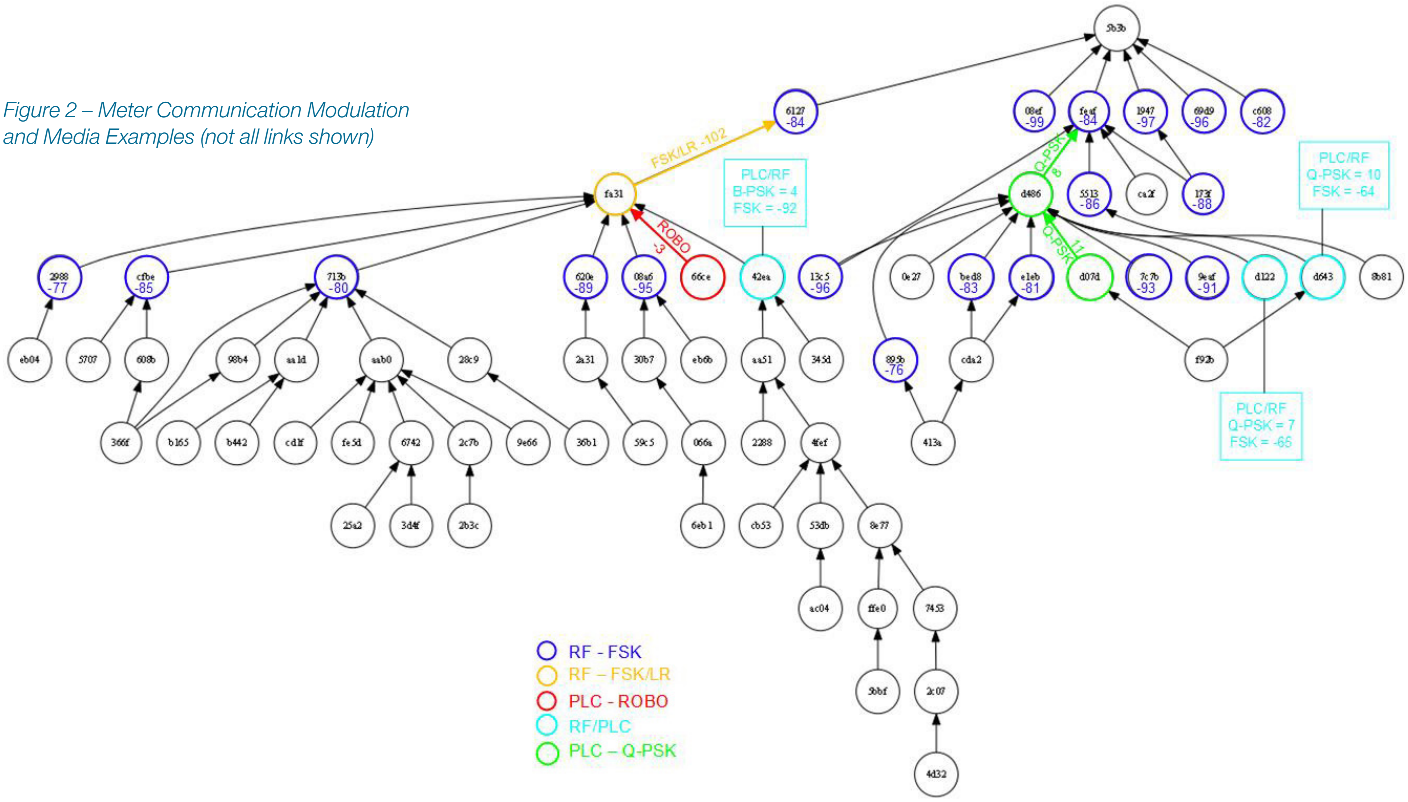


Figure 1 – High Rise Complex Meter Installation Layout

CONNECTIVITY

Connectivity within the high-rise complex was achieved using multiple media types and modulation techniques. Throughout the course of the test, all media and modulations were required to connect 100% of the meters at this site.

Figure 2 – Meter Communication Modulation and Media Examples (not all links shown)



TOWER 2 CONNECTIVITY

To provide connectivity between the Field Area Router on the ground floor and meters in Tower 2, a Q-PSK PLC link was the preferred modulation selected by the technology to connect from the ground floor meter room, through the car park and up to the 11th floor meter room in Tower 2.

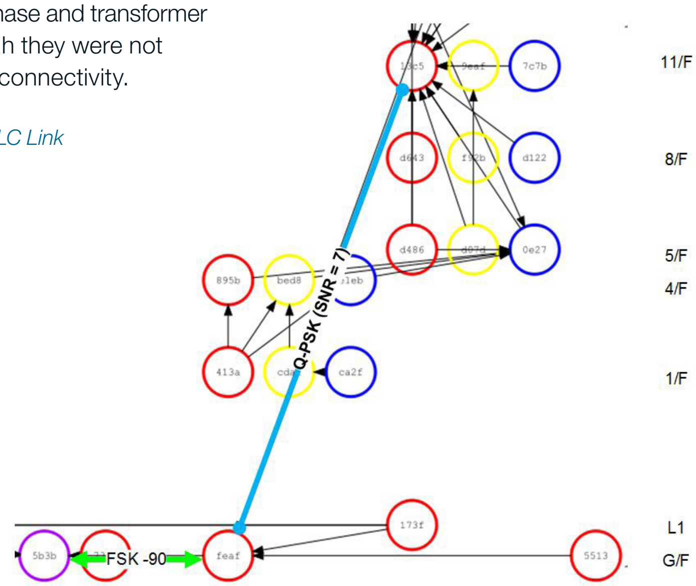
Regularly, other link modulations were chosen depending on the level of power line noise in that environment at the given time. As in Figure 2 (above), at the time of capture, the preferred link was a Q-PSK link to the 5th floor meter from the ground floor.

The adaptation between modulations/ media types and fast handover between them was crucial to the continued reading success of this tower.

Multiple other links were possible from the red phase meter on the ground floor to meters on the same phase and transformer up to the tower, though they were not always necessary for connectivity.

Figure 3 – Tower 2 Key PLC Link

Considering the sparsely deployed mesh in the high rise complex, should the blue and yellow phases be utilised on the ground floor, this tower would have multiple, reliable PLC connectivity paths to the ground floor and therefore back to the Field Area Router.



TOWER 2 CONNECTIVITY (CONT'D)

No RF links were utilised from the Field Area Router on the ground floor to Tower 2 because no meters were deployed between the ground floor and the podium level. This created a void far too large for the RF signal to propagate and make a connection. Although meters existed within these rooms, no ACT meters were deployed within them, which advantageously proved the 'missing link' scenario. The PLC link within this tower was extremely stable, which made connectivity and read rates consistently excellent.

Connectivity within the tower also required multiple different media and modulations. Meters within the same room could connect to each other either using PLC, regardless of the phase, or RF. Very often, meters would use the source of network coming through PLC on a particular phase to travel floor to floor within the same meter stack and then use RF to hop from one meter stack to another.

On occasion, links were observed between the 37th floor and 11th floor. These links could be unstable during high activity periods due to noise on the power line. During periods of heavy power line noise, the system compensated by utilising other routes.

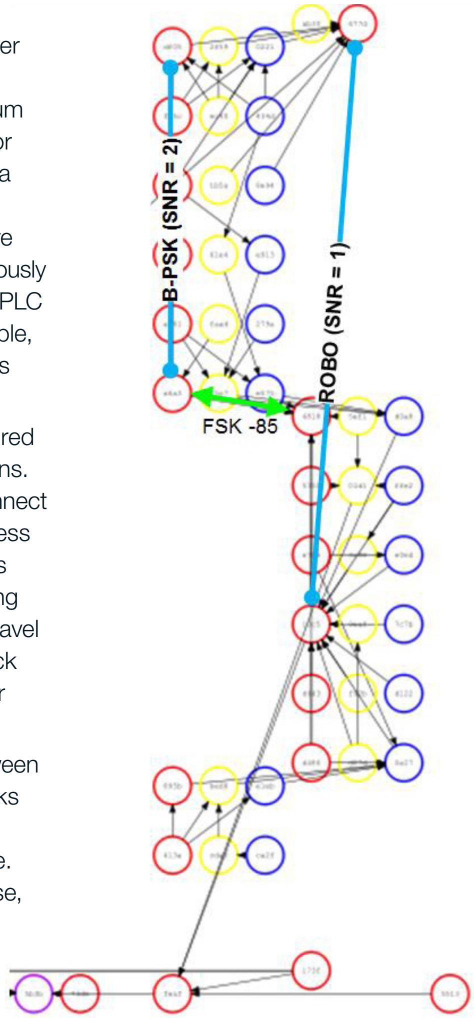


Figure 4 – Tower 2 In-Building Connectivity

TOWER 1 CONNECTIVITY

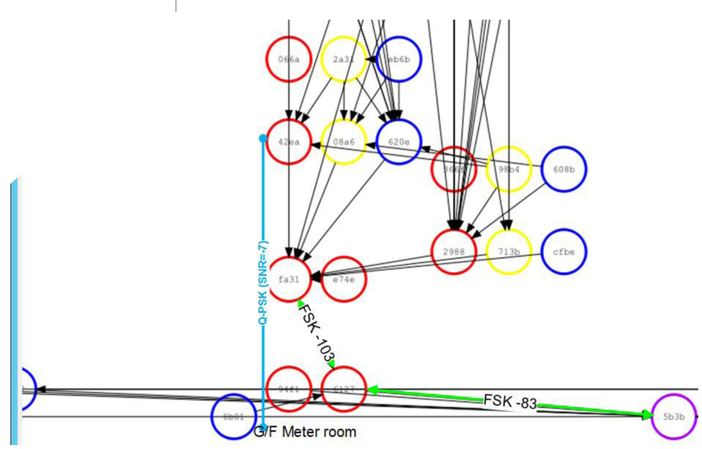
To connect the Field Area Router to meters in Tower 1, an FSK RF link was selected from the meter in the shopping mall (meter room C) to the meter located on the podium floor. This link would sometimes switch from FSK to long range mode depending on variation of the received signal.

An additional two meters were added to the deployment, one in meter room C, as well as one on the podium floor, to provide a redundant RF path amid the changing radio environment. A meter on the ground floor was powered from the wall socket. A Q-PSK link was established between the 5th floor meter room and the ground floor (Figure 5).

PLC was not available to connect the Field Area Router to meters in this tower during the trial, as there was only 3-phase meters available to draw power from and by looking at the deployment diagram (Figure 1) there was an absence of single-phase nodes within the ground floor meter room.

Within the building, nodes would perform similarly to those in Tower 2. Often, PLC links were observed between the lower and higher floors to reduce hop levels, with RF links then attaching to those to make their way back to the Field Area Router. One ROBO link was observed from the 37th floor to the 5th floor, however during periods of higher noise the link would reform to a different node using RF or PLC depending on the better link quality at the given time.

Figure 5 – Tower 2 in-Building Connectivity



SHOPPING MALL

The shopping mall portion of the complex was located on two floors with a total of 6 meter rooms utilised during the ACT trial.

No PLC links were observed, meter room to meter room, and all rooms were connected with RF with the help of the residential tower ground floor meter rooms. The signal strengths between meter rooms were typically strong FSK links with no mitigation required to enable reliable connectivity.

Figure 6 – Shopping Mall Connectivity

READ RATES

Read rate testing was performed for the period of the 23rd to the 29th September 2014. The read rate within this period (and even during the stabilization period of the trial from September 16 to September 22) exceeded the host utility's criteria.

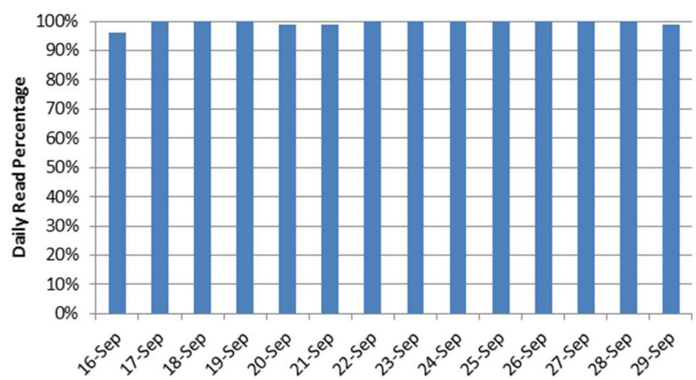


Figure 7 – High Rise Complex Read Rates per Day (one meter represents 0.97%)

TEST RESULTS: LOW RISE RESIDENTIAL BUILDINGS

The low-rise residential building site was selected for its medium density, low-rise apartments and aging meter population. The site's buildings were located in close proximity to each other in a symmetrical, multi-block street grid setting. As a result, meters in separate buildings were not far apart physically.

The deployment in the low-rise residential buildings was also designed to validate the efficacy of ACT in a scenario where aging meters are replaced gradually over time instead of all at once, thus creating a sparsely populated mesh. To simulate this condition, many meter rooms in the site were not populated with ACT devices.

A total of 42 meters were installed, with the Field Area Router being placed within a substation in the centre of the deployment. Several meters were deliberately placed further away from the expected mesh area to challenge ACT's ability to form long range links.

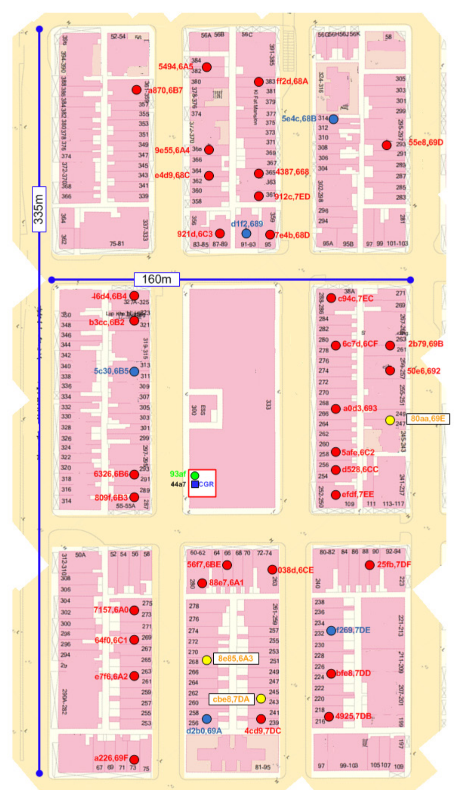


Figure 8 – Low-Rise Residential Building Meter Installation Layout

CONNECTIVITY

Due to the exceptional RF propagation throughout the low-rise residential site and the centralised location of the Field Area Router, the majority of meters formed RF connections. However, there were several examples of connections utilising PLC, usually to achieve higher data throughput to upstream meters. Four meters were deliberately installed in hard-to-reach locations in order to evaluate ACT's long range PLC and RF communication options, and connectivity was achieved using combinations of both.

While already very stable, more meters installed within this area would have significantly enhanced RF mesh robustness and increase the likelihood of more PLC links.

A CLOSER LOOK AT MULTI-MEDIA AND MODULATIONS

The low-rise residential site Field Area Router was located within the main substation in the centre of the deployment area. Although the Field Area Router could form direct links with a large number of meters, each meter evaluated all potential links and considered better options, if they were available.

The images below illustrate the media type and modulations available to the Field Area Router and some sample meters as potential links that could be utilized to communicate with other devices. They clearly show that both RF and PLC media and multiple modulations were necessary to build optimal connections between neighboring meters, in order to form the most stable and highest performing network connections.

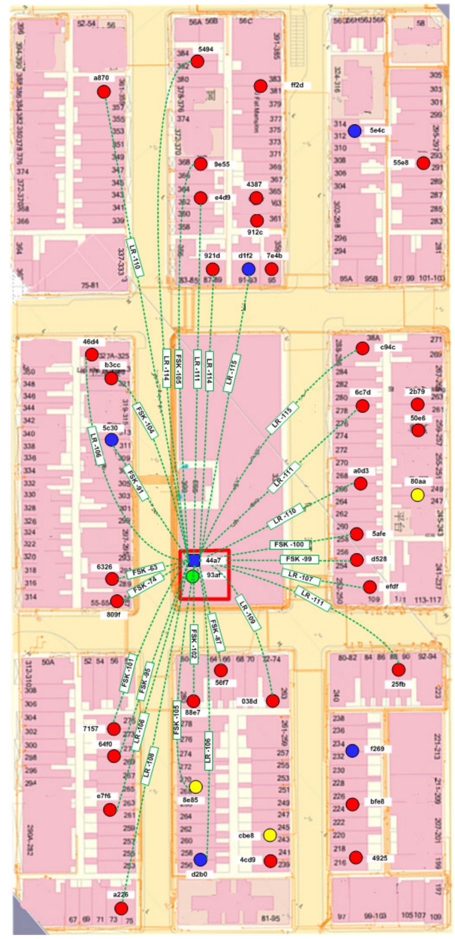


Figure 9 – Low-Rise Residential Site Field Area Router Links

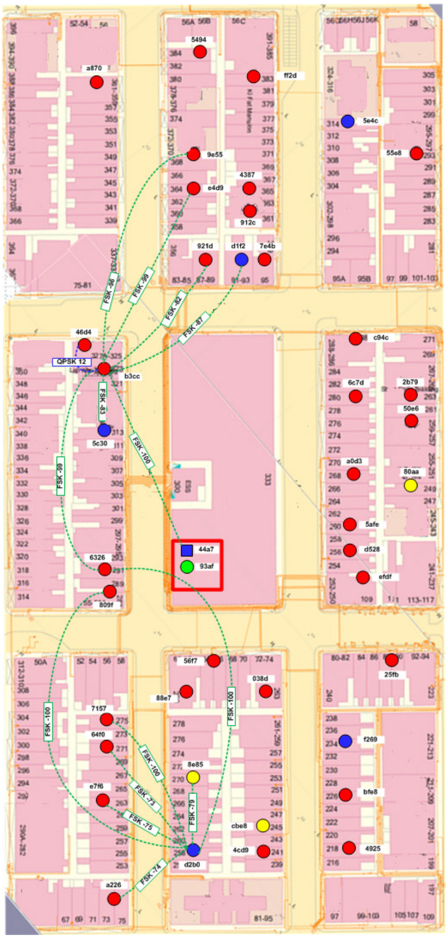


Figure 10 – Meters 5494 and c94c to Neighbours

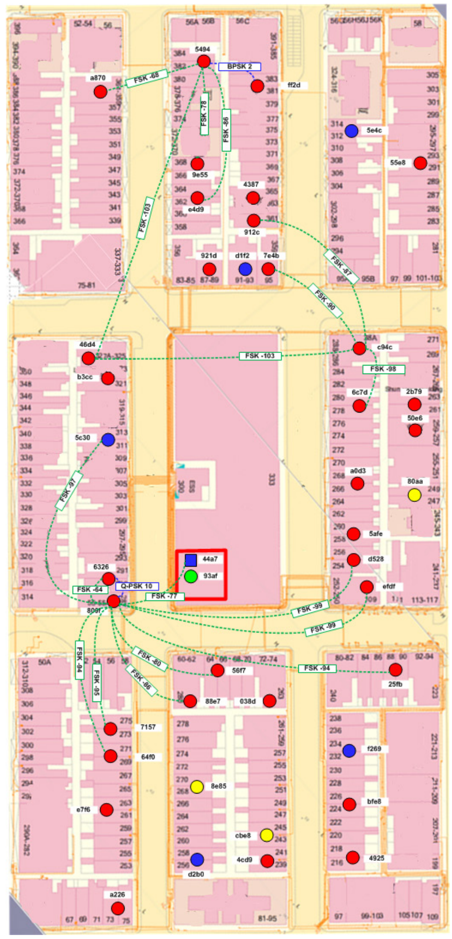


Figure 11 – Meter 809f to Neighbours

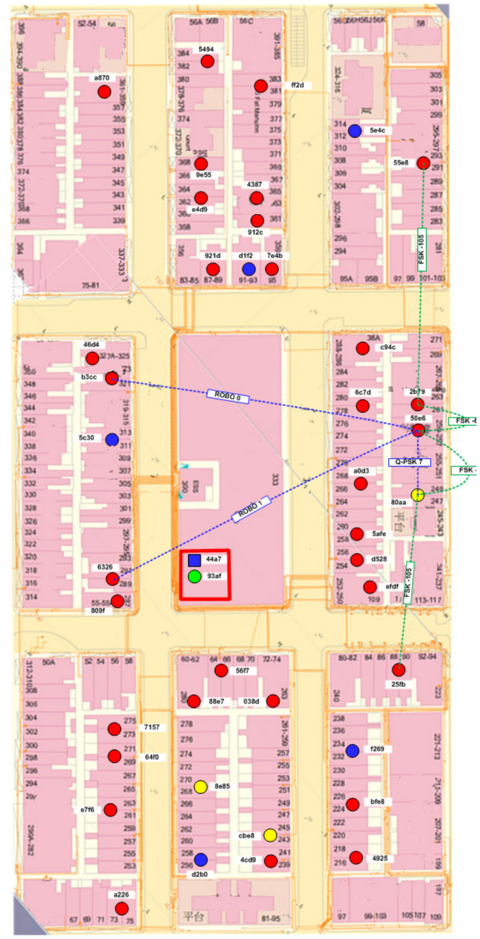


Figure 12– Meter 50e6 to Neighbours and Hard-to-Reach Meters

MESH FORMATION AND 'HOP LEVELS'

Throughout the course of testing, any obvious changes to the formation of the mesh were checked and recorded regularly.

Even with the sparse deployment of meters within the low rise tenement site, the network did not exceed six levels deep and over 50% of the meters were level two or less.

Rebooting the Field Area Router to simulate outages did not illustrate anything uncharacteristic of the formation and the mesh would quickly reform similarly to the way it was when fully stabilised.

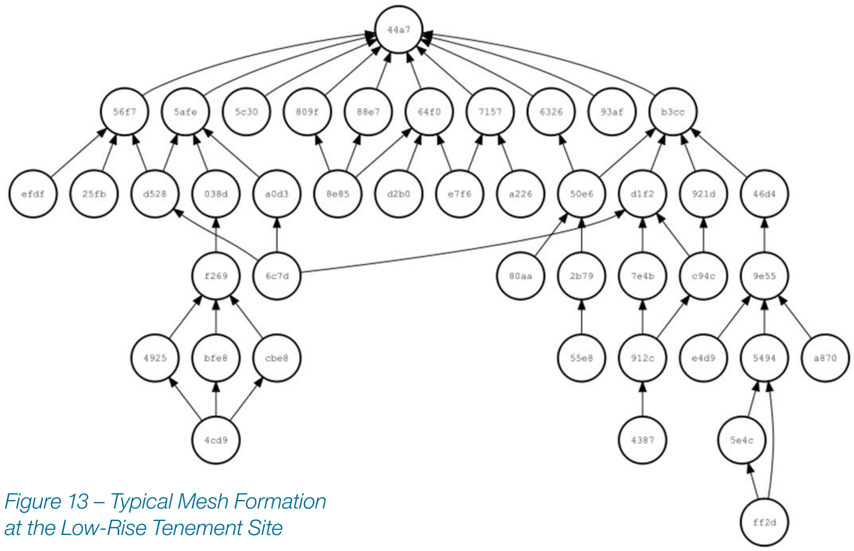


Figure 13 – Typical Mesh Formation at the Low-Rise Tenement Site

READ RATES

Read rates at the low-rise tenement site were very high and quite consistent. Some of the edge meters would occasionally fail to read during an interrogation due to fluctuation of PLC and RF signal during differing times of the day. However, it was almost always the case that, even in this sparsely populated environment, that every meter would be read at least once per day, thus ensuring all data was collected for the day.

To the right are the read rates, including the week leading up to the evaluation period.

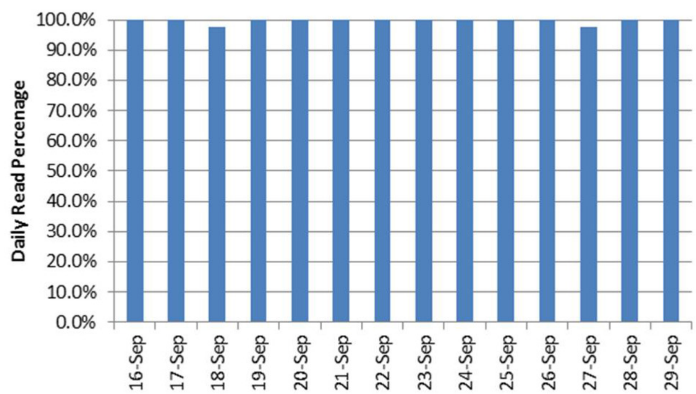


Figure 14 – Low-Rise Tenement Site Read Rates per Day (one meter represents 2.38%)

TEST RESULTS: VILLAGE

The village site was a medium-to-low meter density environment located outside the metropolitan area. The objective of the trial at this site was to evaluate the ability of ACT to operate effectively in a less dense and less urbane environment. To further stress test the communications and simulate an even less populated environment, only 25 meters were installed with several edge meters selected to test long range connectivity. As most phase information was unknown, PLC links were not expected and the surveying was done completely with RF communication in mind.

The Field Area Router in this village was placed on an outdoor pole which had line-of-sight visibility to few meters within the mesh.

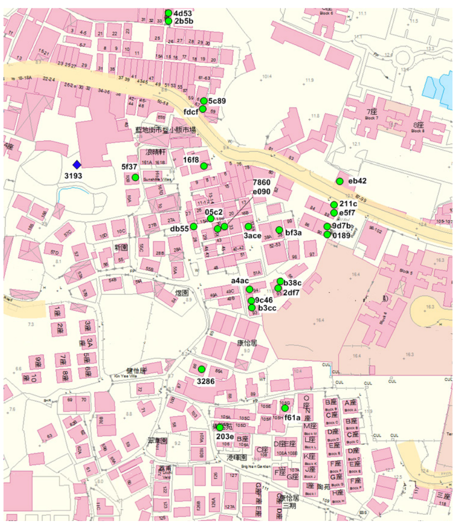


Figure 15 – Village Meter Installation Layout

CONNECTIVITY

Connectivity was achieved mostly with RF FSK communication within the village. This is mainly due to the meters being in close physical proximity to each other and the Field Area Router's height and ability to propagate an RF signal through to many first hop meters.

Further deployment of meters throughout the village would increase the probability for PLC links, though even with the very sparsely deployed mesh here, some PLC links were observed.

VISIBILITY FROM FIELD AREA ROUTER

Almost all meters were able to be seen from the Field Area Router, although not all meters considered this link to be the best available. The height, the omni-directional antenna pattern, and location of the Field Area Router combined to provide solid RF signal penetration throughout the testing area.

The importance of an outdoor unobstructed asset, such as a Field Area Router, provides any village scenario with an added advantage of consistent and strong first hop links. All links below are FSK links and should a sparse deployment situation occur in this particular case, the mesh here is expected to work extremely well.

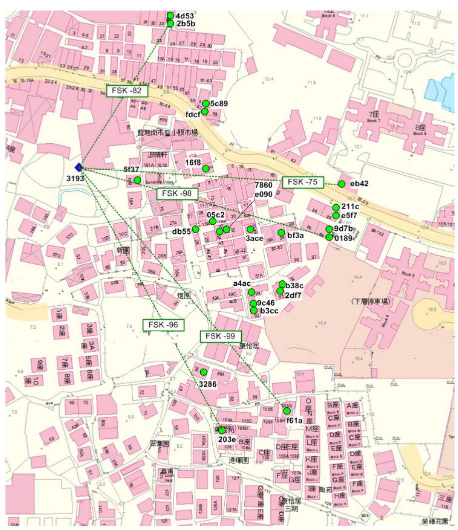


Figure 16 – Visibility from the Field Area Router (not all links shown)

REDUNDANT PLC LINKS

Almost all meters deployed could see at least one meter via PLC at an acceptable SNR (signal-to-noise ratio), with the majority having the option of very good PLC links. As shown below (Figure 22), the mesh network had the ability to expand out of any given node using multiple modulations and media types.

For scenarios like the village site, a cell will form using PLC (and RF) around a transformer and then when needing to hop to another cell will use an RF link to do so. With a higher option for data rate in this scenario, PLC has the ability to make village AMI meters transfer data faster than RF-only deployments.

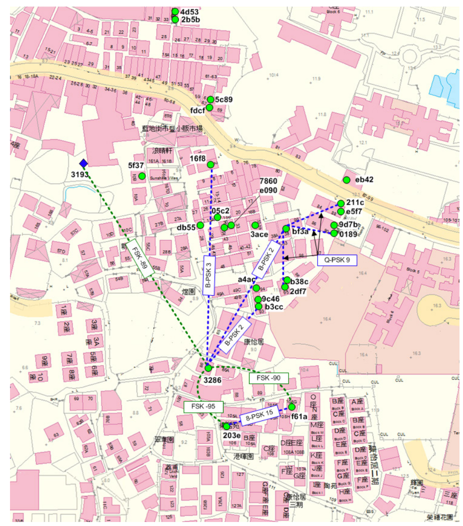


Figure 17 – Multiple PLC and RF Links (not all links shown)

MESH FORMATION AND 'HOP LEVELS'

As with the first two sites, the village site was also monitored for mesh formation. Nothing unusual occurred at this site, with the mesh forming almost exactly the same with each simulated outage.

Mesh depth rarely exceeded five hops and the majority of meters, even with the sparse deployment, were at level two or less.

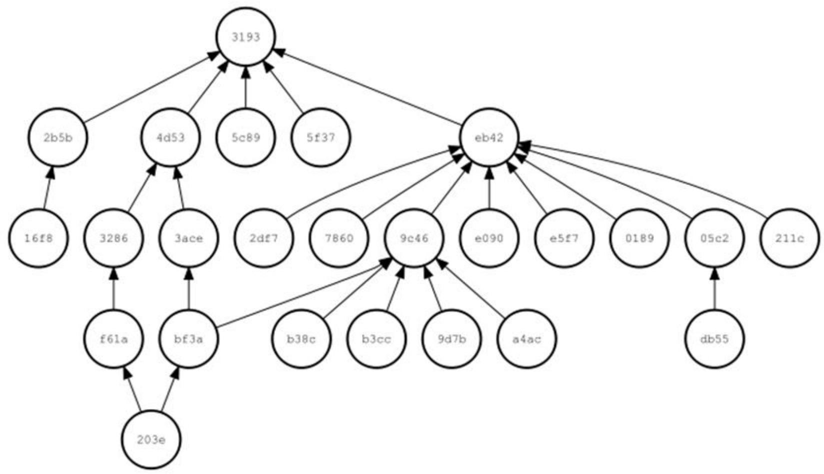


Figure 18 – Typical Mesh Formation at the Village Site

READ RATES

The village site featured very few meters installed in a relatively open area, as compared to the far more urban high rise and low-rise tenement sites and no mitigation was necessary for the village site.

Read rates met or exceeded expectations throughout the testing period. The rates depicted below would not be expected to change significantly should full deployment occur in this village area.

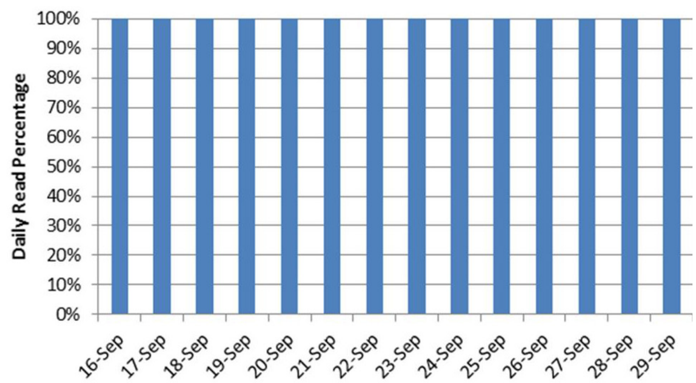


Figure 19 – Village Site Read Rates per Day (one meter represents 4%)

ADDITIONAL USE CASE TESTING

Overview

The host utility and Itron developed several use cases to perform following the connectivity trial tests themselves. Use case testing was limited to the high-rise complex site.

The intent of the use cases was to test specific RF and PLC link scenarios in order to predict the ability of ACT to operate effectively amid other environmental challenges that did not exist in the three trial sites. In particular, the host utility wanted to observe the ability of ACT to form stable building-to-building links within the mesh itself.

Use Case 1: Direct Multi-Tower Links to Field Area Router

The purpose of this test was to demonstrate the connectivity of one tower to another when only needing to hop one level to the Field Area Router.

In this use case the Field Area Router was moved to the 33rd floor of Tower 2 within meter room D and all nodes were left powered up. The Field Area Router was then rebooted to imitate a power outage. After 20 minutes the mesh was 85% reformed with a meter on the 33rd floor of Tower 1 connecting directly to the Field Area Router and propagating the mesh to almost all other meters within the tower. At 30 minutes after reboot, meters had once again selected a higher data rate path and migrated through the lower floors using RF and PLC links. Both towers remained connected in this manner for the duration of this test.

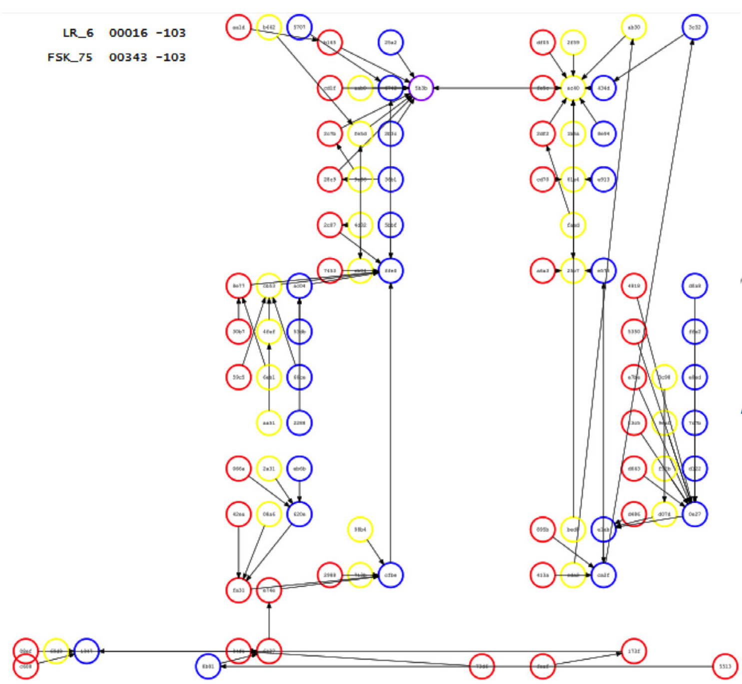


Figure 20 – Mesh Topology (20 minutes after reboot)

Use Case 2: RF Links between Towers

Use Case test two was undertaken for the purpose of establishing multiple radio links directly between two residential towers.

The Field Area Router was moved to meter room C on the 13th floor, in order to not influence meter-to-meter communication, and two nodes on the lower floors had their communications modules powered down to remove the possibility of meters meshing from the lower floors to higher floors in the same tower.

The duration for the testing period was 24 hours.

With this setup, RF links were established on the 1st, 30th and 33rd floors. All links were long range links with RSSI values of -107dBm, -105dBm and -105dBm respectively. Communication links were stable on the network for the testing period and additional meters in this type of configuration would only increase the probably of forming more links tower-to-tower RF links.

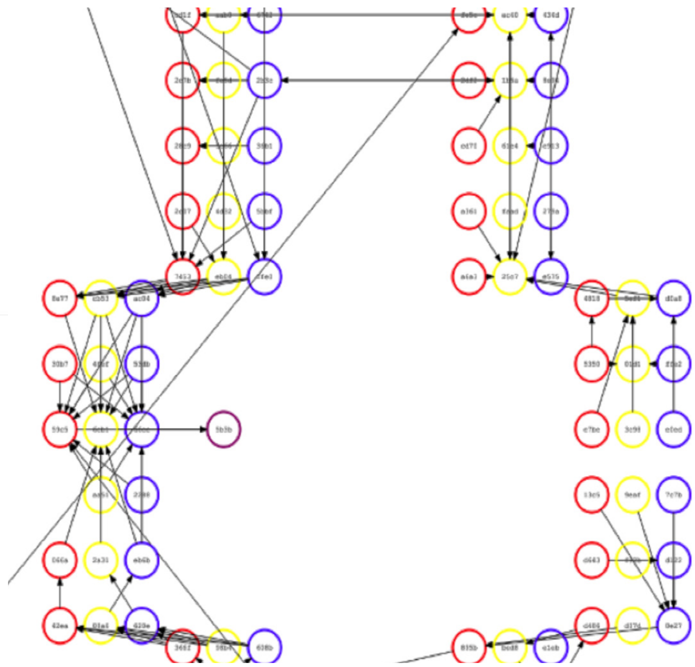


Figure 21 – Mesh Topology: Use Case Test 2

USE CASE TESTING THROUGHPUT

A ping test was also conducted between the two meters connected on the 30th floors. The average round trip time for the 64-byte ping was 455.41ms. Given that the link was formed with the long range modulation, the time taken to send and receive the data is well within the expected time frame and equates to 2.25Kbps on one pipe. ACT supports multiple pipes (more than 12 are supported) running at any given time. The effective throughput, in this example, could easily reach the desired maximum long range throughput of 6.25Kbps.

With many links established throughout the floors of these two buildings, the expected throughput would be enough to pass reading data within a typical 2- to 4-hour read window.

CONCLUSION

The OpenWay Riva ACT communications technology performed extremely well in each of the three scenarios of the field trial, and met the required read-rate targets. The trial demonstrated the value of combined RF and PLC communications on each node to create optimal connections, increased meter-to-Field Area Router ratio, and simultaneously minimised the time and effort required for network optimisation.

Achievements and capabilities demonstrated include:

- Daily read rates >99% for high volumes of load profile data achieved over all three selected scenarios
- Expected ability to connect large meter cells to a single Field Area Router in high, medium and low density urban deployments
  - Inter-building connectivity was demonstrated primarily using PLC
  - Capability of the system to use multiple long-range radio links in conjunction with PLC
  - Meters deployed within the same meter room showed to have high-speed links available between them
  - Network mitigation efforts were significantly reduced
- PLC used to connect hard-to-reach meters in tenement and high-rise sites
- PLC as an alternative to RF in low-density deployments, including tenement and village sites.

ACT also provides a high meter-to-Field Area Router ratio for all three sites:

- In the high-rise complex, two buildings containing 800 meters each were successfully connected together, along with the shopping mall below using only one Field Area Router.
  - A Field Area Router to meter ratio of 1:1,600+.
- Itron recommends a target of 3,000 mains powered devices/ meters (maximum of 6,000 ensure full failover redundancy).
  - A 1:3,000 Field Area Router to meter ratio would be optimal for this location.
- Similarly, in the village site, depending on the layout and how many numbers of meters exist within the village, the recommended cell size would be 2,000 meters.
  - In the trial village site, the conservative estimate of 300 meters total, which exist in this village, shows a Field Area Router to meter ratio of 1:300+. Though this number would likely be quite higher considering the high rise towers nearby, which are expected to join this cell.

Neither a stand-alone RF, nor a stand-alone PLC technology would have been successful in these deployment scenarios or without extensive and costly mitigation efforts. There were clear advantages of having RF and PLC combined in a single mesh for each of the three sites, and these trials demonstrated ACT's ability to deliver "assured connectivity at the highest possible speed" in a range of deployment and use case scenarios:

- In the high-rise site, the most advantageous feature of ACT was confirmed in the cases where RF could not make a reliable connection and a PLC link was leveraged to create a fast (up to 150Kbps) link through nine floors.
- In the tenement site, the FSK RF technology's penetration in a sparse mesh, complemented with PLC for hard-to-reach meters, making connectivity fast, effective and reliable.
- In the village site, the additional radio sensitivity and high-speed PLC links significantly increased read interrogation return times.

In this field trial, the ACT communications technology was only used to connect two buildings. In other real world cases, PLC can also be used to connect basement meters, light pole meters or switch room meters where RF-only communication will be challenged.

Ultimately this trial successfully demonstrated that ACT has two distinct communications features. In areas where RF links were unavailable, PLC can provide fast, reliable communication. Alternatively, in areas where PLC links were most favourable, RF links were used to hop across phases, transformers, buildings and meter rooms. This not only created a larger, more stable and versatile mesh, it also significantly improved meter-to-Field Area Router ratio, reduced or eliminated mitigation efforts and solved many of the connectivity difficulties experienced in the host utility environment.

Appendix A – Equipment Specifications

OpenWay Riva Adpative Communications Technology (in Meter)

RF:

- Output power (average): 29-29.5 dBm
- Best FSK link sensitivity: -103 dBm. Total Isotropic Sensitivity (TIS): -98 dBm
- Best LR Link sensitivity: -114 dBm. Total Isotropic sensitivity: -109 dBm
- Antenna efficiency: -2 dB. Antenna Gain 2.9 dBi (including directivity and efficiency)
- Frequency band: 920-925Mhz (11 Channels; 400kHz Spacing)

PLC:

» Output Level (Maximum) : 123 dBµV
» Output Level (Average on 2 Ohm load) : 114 dBµV
» Best D8PSK sensitivity : 44 dBµV
» Best ROBO sensitivity : 30 dBµV
» Frequency Band : 154.7-487.5 kHz

Cisco Connected Grid Router with Itron ACT PIM Module:

» RF Transmit Power: 28 dBm
» Frequency band: 920-925Mhz (11 Channels; 400kHz Spacing)
» Antenna Gain: +5dBi Omni directional

MODULATION TYPES AND DATA RATES

RF:

» FSK – 75Kbps
» LR – 6.25Kbps

PLC:

» 8-PSK – Up to 200Kbps
» Q-PSK- Up to 150Kbps
» B-PSK – Up to 75Kbps
» ROBO – Up to 23Kbps

APPENDIX B – DEFINITIONS

Abbreviation	Definition
Field Area Router	Cisco's 'Connected Grid Router' or 'CGR'
ACT	Adaptive Communications Technology
RF	Radio Frequency
PLC	Power Line Carrier
SNR	Signal to Noise Ratio
FSK	Frequency Shift Keying Radio Frequency
LR	Long Range Radio Frequency
8-PSK	8-Phase Shift Keying
Q-PSK	Quad-Phase Shift Keying
B-PSK	Bi-Phase Shift Keying
ROBO	Robust PLC modulation
dBµV	Decibel-microvolt
dBm	Decibel-milliwatts
dBi	Decibel-Isotropic
Mhz	Megahertz
kHz	Kilohertz
Kbps	Kilobits per second

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