ALERT2™ transmission protocol, next generation real-time hydrologic monitoring standard.

James Logan
USA NHWC TWG Member for OneRain, 1531 Skyway Drive, Longmont, Colorado, USA
E-mail: james.logan@onerain.com

Robert Thompson
USA NHWC TWG Member for Bureau of Meteorology, 700 Collins Street, Docklands, Victoria, Australia
E-mail: r.thompson@bom.gov.au

Ilse Gayl
USA NHWC TWG Founding Chair and Member for OneRain, 1531 Skyway Drive, Longmont, Colorado, USA
E-mail: ilse.gayl@onerain.com

Abstract:

ALERT (Automated Local Evaluation in Real Time), also called ERTS or ERRTS, has been the real-time monitoring standard radio protocol for the hydrologic warning community for almost 40 years. ALERT has proven invaluable, monitoring both flooding and drought. ALERT has many benefits; an open standard that uses low power at remote sites, it enables robust radio paths and allows for redundant receive locations. ALERT drawbacks include its limited range of sensor ID's (0-4096), integer-only data values between 0 and 2047, 300-baud transmission speed, and data damage and loss due to message collisions. User demand for higher quality data, faster transmission, less data loss, more sensor IDs and more complete data types led the hydrologic community to design a better solution.

In 2006, the USA National Hydrologic Warning Council (NHWC) convened telemetry experts from multiple public agencies and commercial providers to form the ALERT2™ Technical Working Group (TWG). The TWG's mission was to develop a next generation open standard protocol for hydrologic monitoring that retains the benefits of ALERT, overcomes its weaknesses, and offers expanded functionality. The result is a new open public standard protocol that brings the benefits of modern technology yet is backward compatible with ALERT, allowing user agencies to make a staged, economically graceful transition through hybridized systems. The Australian Bureau of Meteorology has been represented on the TWG to help ensure International and Australian requirements are supported.

With initial upgrades four years ago, ALERT2-compatible hardware and software products are offered today by multiple competitive suppliers and are being rolled out by about a quarter of the ALERT user agencies in the USA. Australian agencies have begun evaluating ALERT2 upgrade options.

We present an overview of ALERT2, its differences from and specific advantages with respect to ALERT and ERTS/ERRTS. We review actual deployments, including transition paths, network planning considerations and observed performance.

Keywords: alert,alert2,erts,errts,nhwc,hydrologic,flood,openstandard,protocol,real-time,telemetry.

1. INTRODUCTION

ALERT (Automated Local Evaluation in Real Time), also called ERTS or ERRTS (Event Radio Reporting Telemetry System), has been the real-time monitoring standard radio protocol for the hydrologic warning community for almost 40 years. ALERT has proven invaluable, monitoring both flooding and drought. ALERT has many benefits; an open standard that uses low power at remote sites, it enables robust radio paths and allows for redundant receive locations. Due to its length in service it is now seen as a legacy system in comparison to latest available technology.

The purpose of this paper is to review ALERT's success and its limitations, describe the formation of the ALERT2™ Technical Working Group standard body, outline the new ALERT2 protocol and its new functional advantages, and describe upgrade paths for ALERT-based systems.

1.1. ALERT: History and Status

In the early 1970s, a few USA National Weather Service (NWS) California-Nevada River Forecast Center (CNRFC) hydrologists in California were working on better ways to access hydrology and rainfall data for estimating runoff and forecasting flood peaks. Automated methods then available were expensive and did not provide data in real time. Then, 237 people were killed in a 1972 flash flood that also substantially damaged Rapid City, South Dakota, USA. This lead to CNRFC hydrologists developing the new "Automated Local Evaluation in Real Time" (ALERT) protocol in prototype form for testing on the American River in California in 1974 (Stewart, 1999).

The simplicity, robustness and low cost of the new ALERT protocol were unprecedented. Each station would report immediately any change – increment in rainfall or threshold change in level – as a broadcast radio transmission that could be translated and displayed by any base station computer with a radio and running ALERT-capable software. Because the very short transmissions (usually < 1-second for a sensor report) were simply broadcast on VHF or UHF radio bands, the gauging sites could be powered using small 12-V batteries. Rain-only sites could run without charging for up to a year at a time in regions with lower rainfall averages, and sites with more frequent transmission requirements could be supported by solar panels. Because information was broadcast, many receive locations could be listening simultaneously without any degradation of channel capacity. Because the protocol was wireless, it could be deployed anywhere within radio range and use repeaters to re-broadcast the data where needed, regardless of whether land-based telecommunications facilities were available and without any recurring cost.

By 1977, Monterey County, California, and in 1978, Denver's Urban Drainage and Flood Control District (UDFCD) with Boulder County, Colorado, had installed the first automated gauging networks to measure and transmit real-time precipitation and water level data. The primary purpose was to provide flood threat recognition to local agencies and quantitative weather data to USA NWS forecasters. In 1981, USA Congressional legislation funded operation of the first "Integrated Flood Observation and Warning System" (IFLOWS) networks in Virginia, West Virginia and Kentucky. IFLOWS was built, also by the NWS, on a multi-station hardware and software network that used ALERT radio protocol and upstream telephone links to collect local data into NWS offices for flood warning that later extended to 13 states. The term "IFLOWS" is also used in Australia where the protocol variation that includes a cyclic redundancy checksum (CRC) value ("EIF" or extended IFLOWS format) is commonly used. By the 20th century's end, ALERT-based systems were operating in most of the 50 USA states.

In 1988, a pilot project on the Werribee River was completed by the Bureau of Meteorology using hardware from Sierra-Misco, a USA company that had "spun off" from the NWS ALERT team (Rushton and Wilson, 1989). Within a short time, Elpro Technologies (then Cooper Industries, now Eaton) became the leading Australian supplier of "Event Reporting Radio Telemetry System-" (ERRTS-) compliant technology, using the ALERT protocol and adapted to comply with Australian radio spectrum-use requirements. There is a slight difference between the USA and Australian ALERT implementation; within Australia, different mark/space tone frequencies are used based on the CCITT v.21 standard. The Bureau of Meteorology created and supplied Enviromon software to agencies charged with collecting and reporting hydrologic data; Enviromon was used to create a modern (ERTS and UDP-based) national data collection system as USA's IFLOWS was intended (Thompson, 2010).

A critical benefit of the ALERT protocol development was the fact that it was created as an open, non-proprietary standard. The USA NWS published a description of the standard in an internal hydrology handbook, defining how messages should be encoded and transmitted on VHF or UHF spectrum bands designated for hydrologic use, but much of the documentation was provided by early vendors.

The NWS also offered free software, HydroMet, to qualifying public agency users for the first couple decades. Numerous commercial entities offered hardware and/or software based on ALERT (Besides Sierra-Misco and Elpro there were and in many cases are still: EG&G, FutureTech, Handar-Vaisala, DIAD-OneRain, High Sierra Electronics, Intermountain Environmental-Campbell Scientific, Design Analysis-WaterLog-YSI-Xylem, NovaLynx-HydroLynx, HydroLynx-TriLynx, DataCommand-DEC Data Systems, Rugid. There may be others we have failed to include - apologies). There are many mixed-vendor systems in the world that interoperate very well today, thanks to the standard.

The market for high-quality, real-time hydromet data has thus developed as a strongly competitive environment, enabling real-time monitoring systems to be built and expanded economically; any hardware or software component from one vendor could be replaced by newer, cheaper, more functional products from a variety of vendors. Not only was flood threat recognition enabled for many communities, the competing providers drove the capability of data acquisition, display, alerting and dissemination into new and broader territory. USA ALERT-based networks have expanded and evolved to provide real-time environmental data for a wide array of use cases, including flood and severe weather threat recognition, water resource management, dam safety, stormwater and wastewater management, hydropower operations, irrigation, fire weather, drought and water quality monitoring, to name some. Similarly in Australia ALERT is deployed at over 2,600 sites, 5900 sensors either solely owned or shared by local, state and federal agencies across every State and Territory within Australian. However, not all potential uses in this domain can be satisfied if they are constrained to using ALERT; data resolution, quality and completeness are difficult as the application areas and numbers of users grow.

In summary, ALERT/ERRTS has brought many benefits; it is an open standard that uses low power at remote, relatively low-cost sites, it enables robust radio paths, it offers resiliency for some lost rainfall reports, and it allows for redundant receive locations. Built on the use of dedicated radio spectrum rather than recurring-cost commercial telecommunications networks, vital information is available to authorities during the very emergencies that bring those commercial telecommunications networks to their knees.

ALERT's drawbacks have emerged in large part as a result of its long standing, its steady adoption, and society's ever-increasing needs for real-time environmental monitoring. Constraints include:

- Original, now very slow transmission rate – 300-baud was pretty speedy in the 1970s
- Limited sensor ID pool – 8192 unique sensor identifiers, not enough for today's networks of networks
- Integer-only data values between 0 and 2047 – very low data resolution, reliance on externally-maintained metadata to translate content makes data integrity fragile
- There is little error detection and no forward error correction – software possibilities to process damaged messages are limited by the meager information available
- Data damage and losses, sometimes very high, due to message collisions – sites report independently and as more sites use a radio channel, data loss can increase dramatically

Several long-time ALERT experts began the effort to upgrade in the late 1990s. In 2006, the USA National Hydrologic Warning Council (NHWC) convened telemetry experts from multiple public agencies and commercial providers to form the ALERT2™ Technical Working Group (TWG). The TWG's mission was to develop a next generation open standard protocol for hydrologic monitoring that retains the benefits of ALERT, overcomes its weaknesses, and offers expanded functionality.

The result is a new open public standard protocol that brings the benefits of modern technology yet is backward compatible with ALERT, allowing user agencies to make a staged, economically graceful transition through hybridized systems. The Bureau of Meteorology has been represented on the TWG since early on to help ensure international and Australian requirements are supported.

1.2. Description of ALERT2

ALERT2 leverages many capabilities of today's modern communication protocols to vastly improve performance over ALERT. The ALERT2 protocol is defined fully in a series of documents that encompass the complete specification. The standard documents can be found via http://ALERT2.org.

ALERT2, unlike ALERT, is built on an architecture that is consistent with modern network protocols. Characteristics include standard layering of a protocol stack to enable modular upgrades to various layers over time and technology evolution.

Figure 1 (below) shows the working interactions across Application, Media Access Network Transport (MANT) and AirLink (includes FEC processing) layers of the ALERT2 protocol stack.

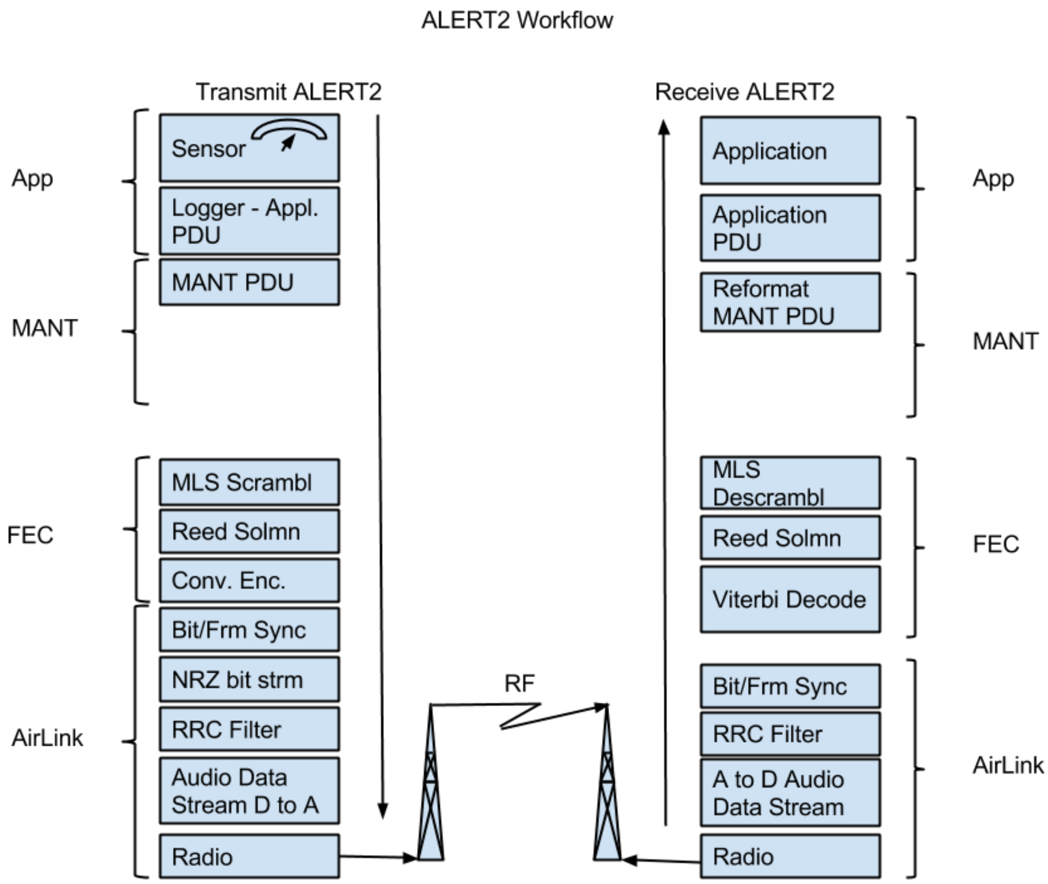

Figure 1 – Workflow across ALERT2 protocol stack layers

ALERT2 features summary:

- 4,800 bits per second data transmission rate
- Forward error correction – many errors can be corrected at the receive site
- Error detection – receivers recognize uncorrectable errors and correctly reject damaged data reports
- Both TDMA and ALOHA transmission modes (see below)
- Site identifiers available to enable 65,535 unique sites
- Sensor IDs within a site are 0 - 255, supporting a theoretical total of 16,777,216 sensors
- Advanced data types (1-, 2- and 4-byte signed and unsigned integers, 4- and 8-byte floating point, timestamps)
- Application layer includes General Sensor Report, Tipping Bucket Rain Gauge, Multi-Sensor Report
- ALERT/ALERT2 Concentration – Supporting ALERT gauges with ALERT2 repeaters: the old ALERT gauging sites achieve 14 times more bandwidth efficiency simply by packing the ALERT reports into ALERT2 for their second hop (see Figure 2, below)
- Test flag – maintenance activities can be identified from the field
- Extensible – protocol allows for improvements over time

1.3. ALERT2 Protocol Advantages

The current ALERT2 protocol version meets all of its original design goals. It was intended to take advantage of modern technology while maintaining backward compatibility with ALERT. It has overcome many of the weaknesses of ALERT, including carrying higher-resolution information with much faster throughput, eliminating data loss due to message collisions, eliminating incorrect data reports, expanding the ALERT ID name space that had been exhausted in several regions, improving previously inefficient use of radio spectrum. As can be seen in figure 2 ALERT takes sixteen seconds to transmit fifty reports in comparison to the improved ALERT2 protocol which only takes two seconds.

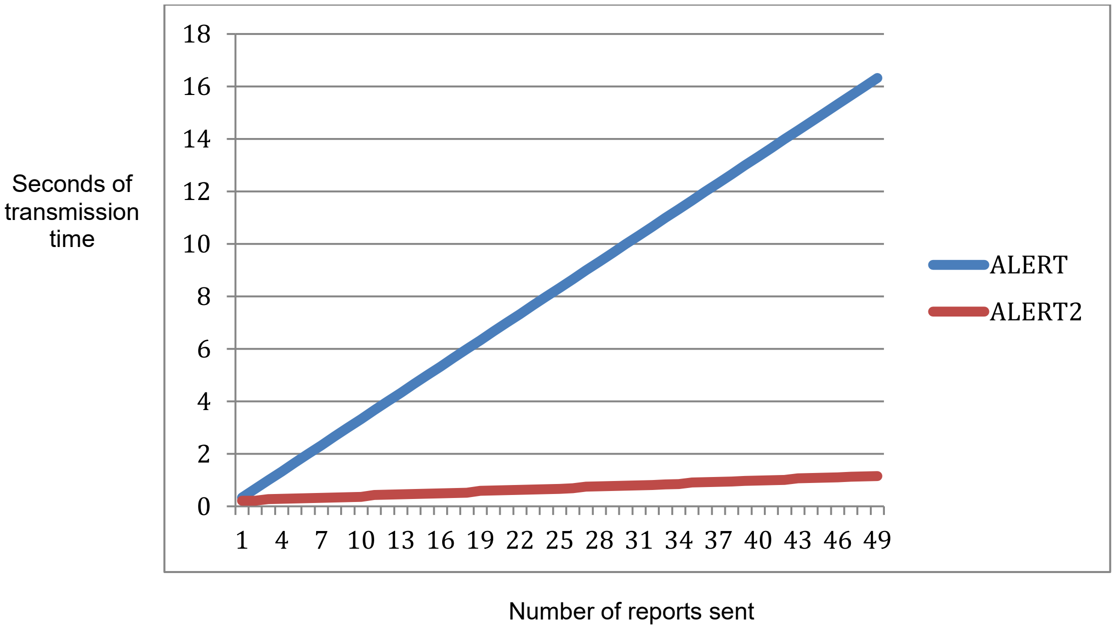

Figure 2 – ALERT gauges with ALERT repeaters vs. ALERT gauges with ALERT2 repeaters

Reduce or Eliminate Collisions. ALERT2 employs time division multiple access (TDMA) to increase network capacity and reduce data loss. Although ALERT2 can be implemented in classic ALERT ALOHA mode (random event-based reporting), using TDMA with GPS eliminates collisions; each transmitter knows its proper time to send. Repeaters should always be configured to use TDMA. Figure 3 shows a TDMA frame cycle (for example, 1 minute) two different ways: as a 1-minute circle and as a 1-minute-long rectangle. Each has its uses in tracking assignments. The frame is divided into individual gauge transmissions (blue), repeater transmissions (yellow), and unused slots (white).

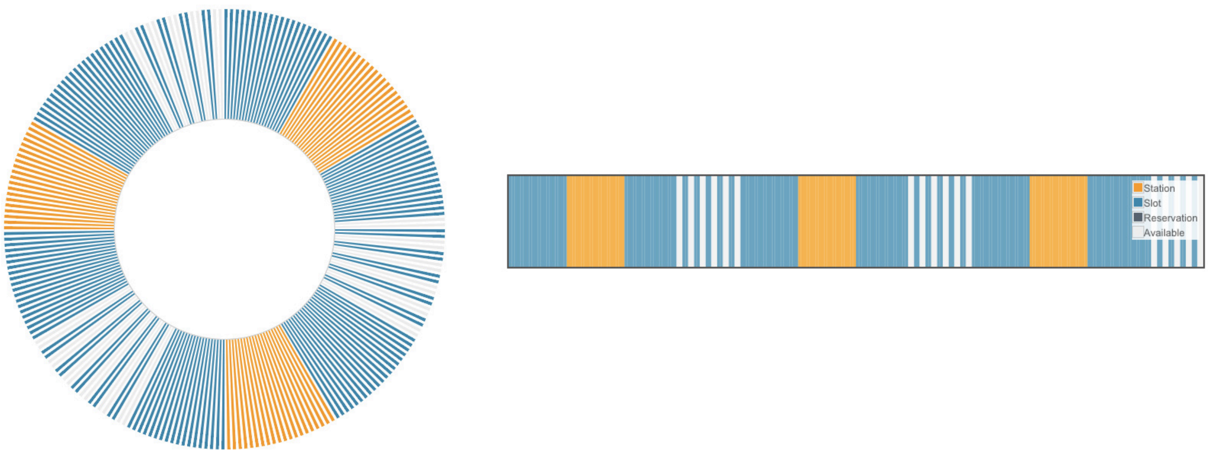

Figure 3 – Two depictions of a 1-minute TDMA frame with gauge, repeater and unused slots.

ALERT2 Concentration. ALERT2 repeaters can receive both ALERT and ALERT2 gauge reports. ALERT network capacity can be increased up to 14 times, depending on traffic, simply by replacing the ALERT repeaters with ALERT2 repeaters. ALERT reports are repackaged and delivered more efficiently and quickly as ALERT2 messages. The entire network has more capacity and eliminates additional errors from repeater to base just by putting the ALERT reports on an ALERT2 second hop.

Increased Gain. ALERT2 uses a RF modulation that improves the detection of bits at higher bit rates. ALERT2 also uses a forward error correction (FEC) algorithm that effectively increases the gain (ALERT2 TWG, 2012). The result of these modulation and coding improvements is to effectively increase gain to compensate for signal to noise ratio losses.

Improved Data Sharing. ALERT2 can transmit data in engineering units. This eliminates ALERT data integrity issues due to separate metadata sharing across agencies; now each receive point can log the correct engineering data directly rather than count on potentially incorrect metadata.

Improved Network Throughput (see Figure 4). It takes about 333 msec to send a single ALERT sensor report. ALERT2 has a much faster transmission rate. Its larger message size and shorter preamble time give it a much higher effective data transmission rate. For example, the top of Figure 4 (below) shows the total time for a single, 3-byte sensor report (ALERT preamble plus message). On the bottom, a 228-msec ALERT2 message carries up to 5 sensor reports. In general, ALERT2 can send about 7 times as many sensor reports as ALERT in a fixed time period, including all the higher resolution, engineering units, bigger ID space, FEC and error detection benefits.

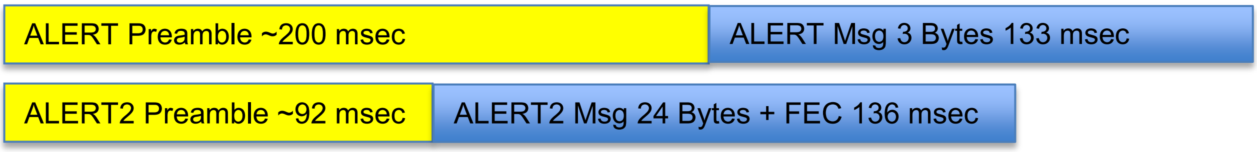

Figure 4 – ALERT and ALERT2 message sizes (in bytes and time) (c.f. Van Wie, 2011)

No More Bad Data. ALERT2's forward error correction and error detection capability means that some errors in the data are fixed, and if they cannot be fixed the receiver knows that and can correctly discard the bad data. Data are correct as transmitted or they are discarded – so, no more bad data.

Other ALERT advantages maintained or improved by ALERT2:

- Very low power – Runs on battery and solar power
- Network resiliency – A properly designed network eliminates single points of failure
- Open standard – Multiple vendors – already many ALERT2 vendors today
- Backward compatibility with ALERT – graceful transition over time makes economic sense

1.4. Phased Upgrades

ALERT2 was designed to be backward compatible with ALERT. This compatibility enables agencies to upgrade from ALERT to ALERT2 in planned phases and the system to operate throughout the upgrade, thus spreading effort and budget required to upgrade over whatever period makes sense.

In general, the sequence to upgrade an existing ALERT network upgrade is:

1. Upgrade base station software to support reception of ALERT2 (depending on network upgrade path, software may need to receive ALERT2 and ALERT concurrently)
2. Ensure data feeds to partner agencies over IP
3. Install parallel ALERT2 receive equipment at base station
4. Upgrade repeaters to ALERT2 repeaters (which serve both ALERT and ALERT2 gauges)
5. Upgrade gauges to ALERT2 as budget permits, perhaps over years.

As soon as the repeaters are upgraded to ALERT2, the network improves significantly, with better throughput and no new data errors or collisions on repeater to base station links (see Figure 5).

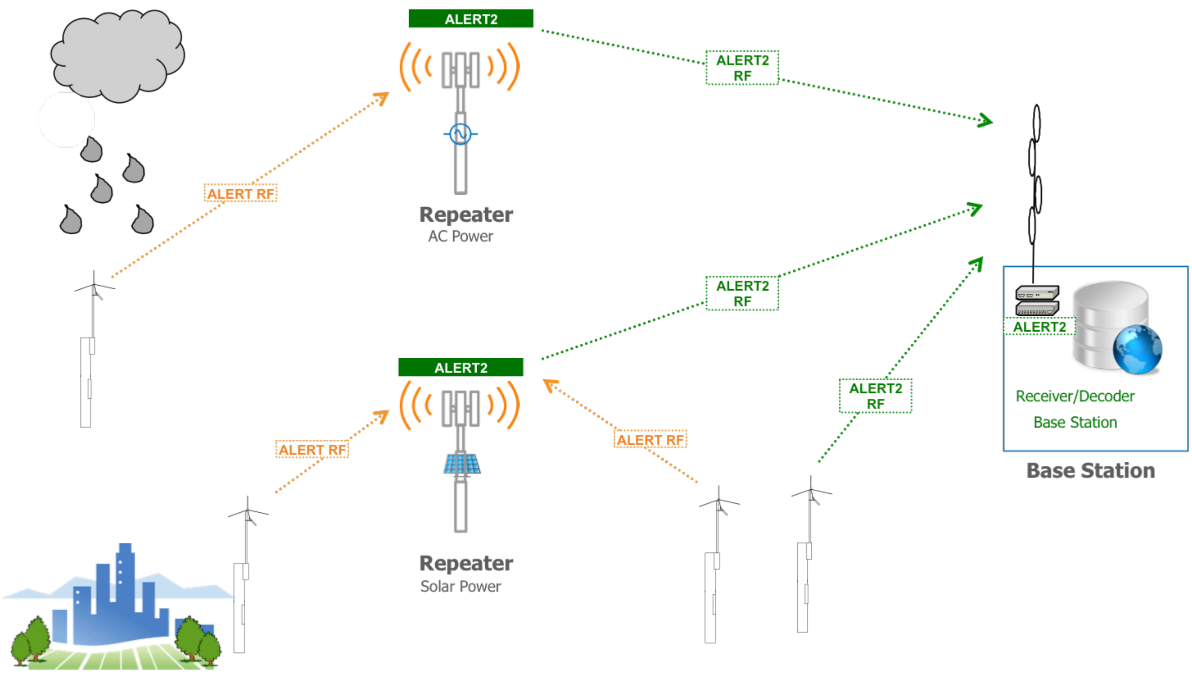

Figure 5 – ALERT2 Upgrade in progress (Logan, 2015)

1.5. Conclusions

The ALERT2 protocol has embraced the original advantages of ALERT and successfully addressed its shortcomings. With its increased system capacity, better data resolution, ability to transmit data in engineering units for shared agency use, absence of bad data and modern layered protocol stack, ALERT2 is broadly useful for diverse data collection applications. The protocol stack-based architecture will allow easier integration with standard IP-based network architectures. Because of its higher functionality, ALERT2 is well-suited not only for flood warning application but also for more diverse water and environmental monitoring, enabling agencies to consolidate field networks with the benefit of real-time event and scheduled (if required) reporting, and thus achieving higher performance at lower cost.

ALERT2 is governed and developed through the National Hydrologic Warning Council ALERT2 Technical working Group with broad member representation. It is an open standard with no licensing or restrictions for implementation by vendors. Extensions to the ALERT2 standard currently in the planning stage are encryption, two-way (duplex) communications allowing control, and introduction of a non-radio transport layer such as Internet protocol. These extensions will vastly increase the number of potential adopters for this technology. Of note, automated road and bridge flashers and gates based on sensed water level are used with ALERT telemetry in the USA. ALERT2 has great potential for expanding use in this domain in USA and Australia.

ALERT2 has already established momentum in the USA with nine ALERT2 systems in partial or full operation in nine different states. The California Division of Water Resources is now funding the planning and implementation of ALERT2 upgrades to more than 25 networks comprising upwards of 4,000 ALERT gauge sites.

There are almost as many ALERT2 vendors today as there were ALERT vendors throughout the 4 decades. AFWS Distinctive Designs, Blue Water Design, Campbell Scientific, DEC Data Systems, High Sierra Electronics, HydroLynx, J.E. Fuller, OneRain, Telos Services, TriLynx, and Water and

Earth Technologies offer ALERT2-compliant components, software, professional services, and/or end-to-end solutions. These are vendors we authors know about today and there are likely others that will emerge; the published standard makes it possible to develop new, interoperable and competitive products, perhaps at lower cost than otherwise.

ALERT2 means the next generation of knowledge we gain from environmental monitoring will be more accurate, more timely, more complete, and likely achieved at lower cost than the knowledge we've accumulated previously.

2. ACKNOWLEDGMENTS

Some of this work was conducted with support from and collaboration with the Australian Bureau of Meteorology, the USA ALERT Users Group (AUG), USA National Weather Service (NWS), USA National Science Foundation (NSF) Small Business Innovative Research (SBIR) Grant, and the USA National Hydrologic Warning Council (NHWC).

3. REFERENCES

ALERT2 TWG (2012), ALERT2 AirLink Layer Specification Version 1.1, National Hydrologic Warning Council ALERT2 Technical Working Group Public Interest Documents. http://www.hydrologicwarning.org/content.aspx?page_id=86&club_id=617218&item_id=11986

ALERT2 TWG (2012), ALERT2 Application Layer Protocol Specification Version 1.2, National Hydrologic Warning Council ALERT2 Technical Working Group Public Interest Documents. http://www.hydrologicwarning.org/content.aspx?page_id=86&club_id=617218&item_id=11986

ALERT2 TWG (2012), ALERT2 MANT Protocol Specification Version 1.1, National Hydrologic Warning Council ALERT2 Technical Working Group Public Interest Documents. http://www.hydrologicwarning.org/content.aspx?page_id=86&club_id=617218&item_id=11986

Logan, J. (2015), ALERT2 Network Design, Proceedings of the 2015 National Hydrologic Warning Council Training Conference and Exposition, June 15-18, 2015, Indianapolis, Indiana, USA http://www.hydrologicwarning.org/content.aspx?page_id=86&club_id=617218&item_id=33313

Rushton, J. and Wilson, D. (1990), Technical Paper No. 5. "ALERT" Radio Telemetry Flood Warning. Installation on the Shoalhaven River. http://floods.org.au/wp-content/uploads/Rushton-J.pdf

Stewart, K. (1999), Revelations from 21 years of Providing Flash Flood Warning Support in Denver, Colorado. Paper presented at the 1999 NATO Advanced Study Institute: Coping with Flash Floods, 8-17 November 1999, Ravello, Italy. https://madis.noaa.gov/udfcd/UDFCDALERTGageSurvey-FinalReport.pdf

Thompson, R. (2010), Flood Warning ICP and Data Collection Systems – from a Localised to a Highly Available National Service and Moving Forward. Paper presented at AHA 2010 Conference in Perth, Western Australia, Australia. http://aha.net.au/media/articles/thompson_robert_2010.pdf

Van Wie, D. (2011), A Description of the ALERT2 Protocol, National Hydrologic Warning Council ALERT2 Technical Working Group Public Interest Documents. http://www.hydrologicwarning.org/content.aspx?page_id=86&club_id=617218&item_id=11986