The ALERT Protocol:
Evolving for the Next Millennium

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Introduction

The ALERT message protocol has proven extremely useful for transmitting event-based hydrometeorological data for over 25 years. It relays real-time data from multiple sensing points to multiple monitoring points at low cost with good overall results. Although it has served the weather and public safety communities well, the ALERT protocol also has its shortcomings. These include lost messages, high error rates, a limited range of sensor identifiers and a very constrained data capacity that is complex to interpret. While ALERT has remained essentially unchanged for the last quarter century, the environmental sensing, telecommunications, data processing, and regulatory environments in which it is embedded have all been revolutionized.

Changing the ALERT protocol to increase the sensor identifier range, to allow the transmission of actual sensor engineering values, or to add a robust error detection and correction code will increase the message size. Increasing message size without increasing losses due to data collision will require a higher data rate. Higher data rates in 25kHz and 12.5kHz channels are possible, yet any evolution must address the regulatory, cost, legacy compatibility and standards issues inherent in such a change.

ALERT's Proud Legacy

Since its first implementation, the ALERT protocol has enabled the implementation of flood warning systems, protecting lives and property in many communities. The protocol format was designed specifically for transmitting a single four-digit ASCII payload (sensor ID and value) over a FM-modulated RF (radio frequency) channel when local conditions triggered a sensor. The ALERT protocol adapted audio FSK (Frequency Shift Keying) modulation technology, then widely utilized for 300 bps (bits per second) wireline telephone modems, for use with analog (voice) radio systems. Using widely available 300 bps single integrated chip (IC) technology, vendors were able to develop affordable monitoring systems for hydrometeorologic sensing.

Several elements of the ALERT protocol have been key to its success:

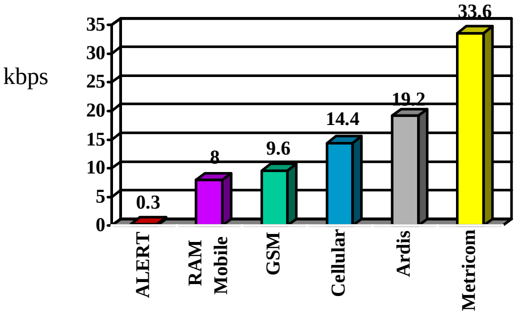
- It is a one-way transmission system. This eliminates the need for costly, power consuming receivers at sensing locations. Multiple, independent receiving locations can simultaneously receive sensor transmissions and process data. No radio channel bandwidth is consumed by sending "polling" messages to remote sensors.
- It is an event-driven and/or timed system. Remote sensors provide real-time notification of events to central monitoring facilities based on conditions at the sensor. Immediate notification improves mobilization time in public safety situations. Power consumption is minimized at the sensing site, since data is forwarded only as needed. Additionally, the remote site has the ability to periodically send site status.
- It is a simple low cost technology. The ALERT community continues to reap benefits because it adopted a protocol standard that allows use of non-proprietary, readily available technology. This enables multiple vendors to offer compatible ALERT systems with the cost benefits of using ICs designed for higher volume industries.

ALERT's Limitations

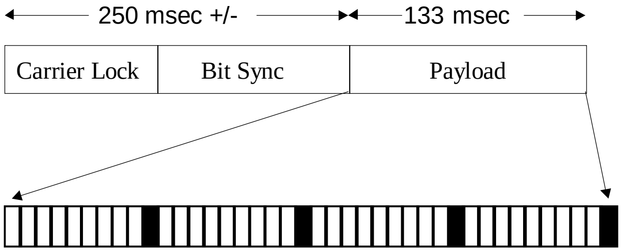
Unfortunately, there are also several disadvantages to the ALERT protocol. These limitations are becoming more apparent as a result of ALERT's success and increased use in larger and more complex data monitoring networks. They are:

- Lost reports. Because sensing sites transmit independently, data will be lost when two sites transmit at the same time. Typically, the message with the weaker signal is lost, but both may be lost on some occasions. The probability of data collisions increases exponentially with the overall transmission rate.
- Corrupted data. Only a small percentage of the ALERT sensors in the U.S. use any error detection. Data collisions, noise, and poor radio path can lead to errors in decoding the message that go undetected. This can cause a data value to be assigned to the wrong sensor or the wrong value to be assigned to the correct sensor. Spurious values can trigger alarms or cause serious confusion or delays in interpreting critical situations.
- Sensor addressing limitations. The original ALERT concept envisioned some number of independently operating, small local systems. The original ASCII ALERT protocol allowed only 99 sensor IDs, and the binary protocol now in use expanded the addressing capacity to slightly more than 8000. With increased data sharing and the use of multi-sensor transmitters requiring blocks of 10 or more addresses, the coordination of address assignment and the sharing of data among systems using identical addresses is increasingly problematic.

- Sensor value limitations. The four-byte ALERT payload limits data values to 2048 integer values, which means interpretation algorithms are necessary at the receiving point to convert transmitted data to meaningful values in engineering units. This limitation also constrains the range or the resolution of the measurement. To use the data at multiple receiving locations, any changes in sensor calibration must be reflected in the interpretation processes at each base station.
- Spectral efficiency. ALERT has remained FSK at 300 bits per second in a 25 KHz channel. Today, readily available technology provides data rates 20 times faster. Some leading edge systems are at more than 100 times the ALERT rate (see the chart below).



Another factor that contributes to the ALERT protocol's low data rate is that each message begins with a non-information-carrying preamble that is significantly longer than the actual data transmission. A typical ALERT transmission requires 0.383 seconds to send the 40 bits of payload (0.250 seconds of carrier lock and bit sync and .133 seconds for 40 bits of information at 300 bps). This provides an effective data rate of only 104 bps, and in a 25 kHz radio channel, this is only 0.004 bps per Hertz of bandwidth!



40-bit payload

The Challenge Facing ALERT

ALERT's limitations and inefficient spectrum use pose significant challenges for the future of the protocol. ALERT users will have to compete for continued spectrum allocation. To meet these challenges, ALERT will need to serve a broader base of users, provide higher quality data, with more efficient use of the spectrum. Since other protocols are being used more widely for the transmission of data, the spectrum is being "refarmed" to accommodate the faster, more efficient, high-volume users. ALERT must evolve to make effective use of narrower bandwidth channels, or it could be forced "off the air."

As we look to the future, we want to

- preserve the random, event-driven architecture that makes ALERT so effective,
- enable ALERT systems to operate in the narrowest possible bandwidth allocations,
- maximize the effective data rate of the individual ALERT message.

The path to meeting these challenges is not as formidable as it seems. Proven technologies already exist that can be adopted by ALERT. Low-cost, high volume, standard components are currently available. Finally, there is a transition path that allows orderly migration to new technologies.

Adopting Current Technology

By adopting current technology in the following areas, the ALERT protocol can be enhanced:

- Improve message information content. Use higher data rates in narrower channels with current RF modulation technology such as Gaussian Minimal Shift Keying (GMSK).
- Adopt open squelch operation with message detection using a long bit-frame synchronization pattern.
- Eliminate corrupted data by using robust error detection technology.
- Reduce the number of lost reports by using forward error correction technology.
- Enhance ALERT's interoperability with other data transmission and hydrometeorological systems by using a layered protocol stack.

The low cost of advanced digital signal processing and high levels of chip integration enable today's RF communication systems to deploy modulation techniques too expensive for use even five years ago. The high volume markets for digital cellular phones, two-way paging systems, digital TV transmission and digital wireless broadband to the home have lowered the cost of advanced technology for the ALERT community as well.

Improved Message Content: GMSK Modulation

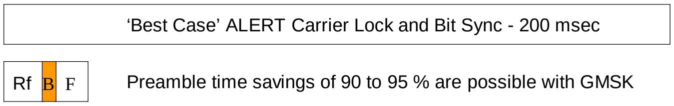
Gaussian Minimal Shift Keying (GMSK), currently used for the GSM digital cellular systems, is one good choice for a new ALERT modulation technology. A constant-envelope modulation method, it is less affected by fading in RF channels than are amplitude modulation technologies such as QAM, and hence it has a lower Bit Error Rate (BER). GMSK theoretically has a lower spectral efficiency than a phase modulation technology such as QPSK, but it also has a major advantage. Because GMSK is a variant of FSK, it can be readily integrated with the RF circuitry used in ALERT transmitters and repeaters. This is not the case for a phase shift modulation technology.

Using currently available integrated circuits, GMSK transmission of 4,800 bits per second in a 12.5 kHz channel is easily achieved. ALERT using GMSK at 4,800 bps provides 16 times the throughput of current ALERT.

Open Squelch Operation

Open squelch operation eliminates much of the "wasted" carrier lock and bit synchronization time. Operating open squelch forces the determination of what is a valid message outside the RF receiver. Identification of a valid ALERT message could be accomplished through the use of a long frame sync bit pattern (on the order of 48 bits). The probability of random noise generating the specific frame sync pattern would occur extremely infrequently (less than once per year). Using error correction and detection in the payload eliminates even those few spurious messages.

The specific reduction in preamble time with open squelch operation is dependent on receiver response times. Conservative estimates for carrier lock, bit sync and frame sync for a 4,800 bps GMSK message are 0.025 seconds, one tenth the typical current ALERT transmission.



Preamble time savings of 90 to 95 % are possible with GMSK

Error Detection and Correction

Adopting a higher bit rate provides additional benefits. One is the ability to use a portion of the increased data capacity to minimize corrupted and lost data. By using standard Forward Error Correction (FEC) codes such as Golay or Reed-Soloman, all 1- and 2-bit errors can be corrected, and more than 99.9% of all errors can be detected. To reduce the impact of multiple sequential bit errors caused by channel fading, a process of interleaving the data and error correcting code bits from separate portions of the message is now widely used in GMSK RF systems. “Off-the-shelf”, low power, GMSK modem ICs that incorporate FEC and bit interleaving are available for only a small premium compared to the FSK ICs used in today’s ALERT hardware.

The data overhead to achieve this would be less than 50%. This would reduce the new 4,800 bps data rate to an effective data rate of 3,200 bps, yielding an order-of-magnitude increase in data rate with huge improvements in data quality and reliability. These enhancements will make ALERT hydrometeorological data highly useful to many users who now find it unacceptable.

Layered Protocol Stack

Advances in data communications such as the Internet are attributable to the adoption of an architecture based on "layered communication protocols." Layered paradigm functions are modularized, and well-defined interfaces are established between the functional layers. Similar to object oriented programming, layered protocol stacks "hide" the details of implementation from other portions. Therefore, replacing a single functional module does not require replacing the entire architecture.

Adopting a layered communication protocol paradigm for ALERT primarily means encapsulation, or packing it in a generic shipping box. For example, when a sensor (the application layer) generates a data message, the sensor passes this message to a network/packet layer. This network layer adds the necessary control mechanisms to provide reliable transport (e.g., error detection code), and sends the encapsulated payload to the data link layer. The data link layer adds the framing (i.e., the bit sync and frame sync preamble) and link control necessary, and passes the newly encapsulated payload to the physical layer. The physical layer does the "bit transport". In the ALERT system, the physical layer controls the RF modulator and transmitter. Then, when the message is received at the base station, the reverse process occurs. None of the layers relies on "knowledge" about the payload that is passed to it from a higher layer.

Using a layered protocol, the flexibility exists to inter-operate with different physical media. For example, an ALERT system could use the data communication capabilities of a LEO satellite network (Orbcomm), an RF polled network, a spread-spectrum packet network, or the traditional event driven RF broadcast network, all without modifying the application layer.

A Sample Protocol

To demonstrate the capability that can be achieved by adopting the above technology, a sample new protocol is proposed, based on the 4,800 bps GMSK technology.

The proposed information payload is 168 bits in length. It contains the sensor location to a resolution of 10 feet, a code for the measurement types and units, and two related measurements from the sensor (such as stage and flow) expressed in engineering units with double precision. This information contained in the message itself allows the receiving base station to interpret and display the data with no previous sensor definition or calibration information.

At the application layer, each sensor, in response to a request or event, generates an information message containing the following (sample message below):

- Sequence Number: 8 bits - Helps to identify missing reports
- Location: 48 bits - Sensor’s global position to 10 ft (high order part of the sensor ID)
- Measurement Type: 16 bits - Definition of measurement and units
- Sensor ID: 8 bits - Low order part of the sensor ID, allowing co-located sensors
- Data: 32 bits - Allows “finished” data
- Correlated Measurement Type: 16 bits - Definition of measurement and units
- Correlated Sensor ID: 8 bits - Low order part of the sensor ID, allowing co-located sensors
- Correlated Sensor Data: 32 bits - Allows “finished” data

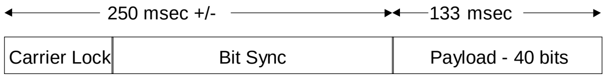
S LLLLLL 003A 04 4. 33 OO3B 04 1090

Either a single sensor 168-bit payload or multiple 168-bit payloads can be concatenated into a single message. The final message is therefore variable in length. The multiple payloads could be generated in response to simultaneous events or could be programmed in the gauge.

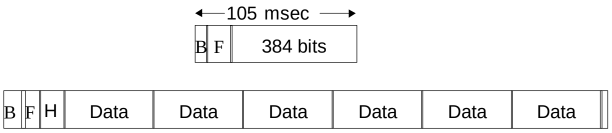
The variable length payload is passed to the network layer, which encapsulates the payload with a suffix and a preamble containing the information needed to interpret the type of payload, route the payload and check for errors in the payload. Notice that the network layer can encapsulate any type and number of payloads: new ALERT messages, traditional ALERT messages, or other message types. The only constraint is that the number of bits in the payload be evenly divisible by four.

The network layer passes its output to the data link layer. The data link layer, using forward error correction, expands the payload by a factor of 1.5, performs a bit interleave, then adds a 64-bit header for bit and frame sync.

The data link layer passes its payload to the physical layer. This layer controls the RF transmitter and modulator. A carrier-only time of 0.012 seconds is initiated, followed by the payload at 4,800 bps.



Above, an “old ALERT” message. Below, a “new ALERT” message:



Six “new ALERT” reports sent in the time of one “old ALERT” report!

This new protocol, for a single sensor payload with all the enhancements inherent in the new protocol (engineering units with error correction, error detection, sequence number, correlated measurement sensor data, geographic location) completes in 105 milliseconds, while a traditional 300 bps ALERT message takes 383 milliseconds.

The reduction in transmission length allows an increase in the number of sensors transmitting on any channel. Even higher efficiency is reached when multiple sensor reports (such as from a weather sensor suite) are bundled in the same message with a single preamble, header, and suffix. Six sensor reports could be sent in the duration of a single report in the present ALERT format.

Next Steps

ALERT's current success is in part the result of standardization. Multiple vendors compete for the ALERT community's business based on functionality, quality, reliability, price and other factors, but all products interoperate. As a new ALERT protocol is developed, standardization remains critical, and continued dialog among users and vendors is critical for the ALERT protocol to evolve and remain viable in the next millennium.

This article is not proposing the "one best", or even a complete solution. The sample protocol discussed here is merely an illustration of the benefits to be gained by reexamining the current protocol. Joint efforts are needed to develop technology alternatives, to prototype and test possible solutions, to define a new standard and to develop suitable system migration paths. Now is the time to start.

A working subcommittee of the National Hydrologic Warning Council Narrow Banding Committee, chaired by Todd Mendell of the NWS California-Nevada River Forecast Center, was established at the San Diego conference in May of 1999. We strongly encourage your comments and participation. Please contact Todd Mendell on email: tm@cnrfc.sac.noaa.gov

Biographies

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