Last-Mile Hazard Warning System in Sri Lanka: Performance of WorldSpace Addressable Satellite Radios for Emergency Alerts

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Abstract - ***The WorldSpace Addressable Radios for Emergency Alerts (AREA) was developed to improve the "situational awareness" of all-hazards for communities at risk. The solution was field tested in Sri Lanka for the first time as part of the Last-Mile Hazard Warning System (HazInfo) research project. The HazInfo project realized that early warning via Information Communication Technology (ICT) had to be a point-to-multi-point application and was best accommodated by Information Communication Technologies [5]. The HazInfo Project further recognized the growing call for the use of a globally accepted content standard: Common Alerting Protocol (CAP) for all-hazards, all-media alert and notification. AREA satellite broadcast system adopts CAP version 1.1. HazInfo project established last-mile networking capability with the AREA sets for 16 tsunami-affected villages and 34 District Centers in Sri Lanka in order to study the suitability for a standards-based community hazard information system. Specific measures were devised to assess the reliability and effectiveness of the technology. Initial field tests indicate that core alerting functions need to be strengthened to improve reliability and usability, but, overall, WorldSpace delivery of alert can serve as a key component in a regional last-mile alerting system. The objective of the scoring system was not to decide whether the technology was a winner but to find out how it can be improved to perform reliably and effectively in the difficult conditions of rural Sri Lanka.***

I. INTRODUCTION

In December 2005, LIRNE*asia*, an ICT policy and reform research organization, initiated a research project to evaluate the "last-of-the-mile" communication component of an all-hazards warning system for Sri Lanka. The project entitled, "Evaluating Last-Mile Hazard Information Dissemination: A Research Project", or the "HazInfo Project", was carried out by a grant from the Canadian International Development Research Center (IDRC). The HazInfo project research design was based on recommendations of a "participatory concept paper" for a national early warning system (NEWS:SL) completed in the months following the 2004 tsunami [6]. The pilot project would involve 32 coastal villages that had been affected by the tsunami and a cross-section of communication technologies intended to assess the potential for extending warning to the last-mile in rural and remote communities.

The *Disaster Warning Response and Recovery* (DWRR) service was launched in January 2006 by WorldSpace (WS) Corporation. AREA is a class of WS Systems that is designed to be used in DWRR. Moreover, using AREA's addressability features, focused warnings can be addressed directly to those communities immediately at risk from hazards like tsunamis, cyclones, floods, dam breaches, etc. Each radio has a unique code and also a provision for interfacing with Global Positioning System (GPS) receivers. This enables hazard warnings to be issued to those units that are known to be within a vulnerable area -- or just to those units with specific assigned codes. It is also possible to personalize and target the message to the specific vulnerable communities. WS Satellite is inherently a digital broadcast medium and can be tailored to provide a variety of one way, one-to-many type of data services offered traditionally as broadband Internet services in the developed world. These include: Multicasting, namely, the distribution of digital contents simultaneously to a Closed User Group (CUG) in multiple locations [3] and [4].

WS has the capacity to easily reach widely dispersed geographic locations and even in areas where there is no telephone connectivity. The limitless reach is further augmented by alternative power-supply solutions that address the lack of connectivity to public electrical power grids as well [4].

A key feature of the project was the use of the *Common Alerting Protocol* (CAP) to enable data interchange between the Information Hub and the technologies. A benefit of CAP is that it is an XML-based protocol with clearly defined elements and values. CAP is a simple, flexible data interchange format designed for collecting and distributing "all-hazard" safety notifications and emergency warnings over information networks and public alerting systems. Essentially, as a content standard, CAP is deliberately designed to be transport-neutral [1].

II. COMMUNITY-BASED LM-HWS ARCHITECTURE

The Community-based LM-HWS architecture depicted in figure 1 complements the traditional public alerting system design usually established by local and/or national governments. By contrast, the LM-HWS project architecture establishes a CUG of first responders, who are equipped with addressable wireless devices for receiving bulletins issued from Sarvodaya[1] Hazard Information Hub. For experimental purposes, the Community-based LM-HWS was designed to replicate the components of the typical NEWS:SL; i.e. a system equivalent to an end-to-end early warning system excluding the "detection and monitoring system". For research purposes the CUG based system illustrated in figure 1 will provide the identical functions of the NEWS:SL, which is an aggregate of the National and Last-Mile Systems. Hence, the model in figure 1 is an ideal replica to test the functional performance of envisaged last-mile component of the NEWS:SL. The analogy between the NEWS:SL and Community-based

A simplified information flow for the LM-HWS is as follows: staff members at the HIH monitor hazard events around-the-clock using the Internet. When a potential threat is detected, the HIH activates its Emergency Response Plan (ERP) by addressing a message to the n-number of communities at risk using a combination of wireless ICTs to reach local first responders (denoted by the yellow double headed arrow between the HIH and ICT-G blocks in figure 1). Each community has assigned a person or persons to be responsible for managing the wireless device and monitoring it for incoming warning messages. This person has received training from Sarvodaya and is designated as a community ICT-Guardian (ICT-G). When the ICT-G receives a warning

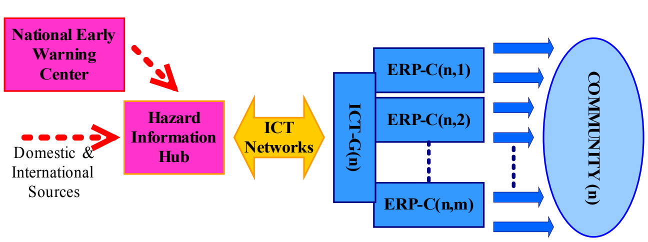

Figure 1: end-to-end hazard information communication architecture of the Community-based LM-HWS; where messages received at the HIH are relayed to the villages.

[1] The Lanka Jatika Sarvodaya Shramadana Sangamaya (Sarvodaya) is Sri Lanka's largest and most broadly embedded people's organization, with a network covering: 15,000 villages; http://www.sarvodaya.org/about.

message at the HIH, they are responsible for activating the community-level ERP. The community response will vary depending on the content of the message, including its *priority* level. During activation, the ICT-G informs the m-number of ERP Coordinators (ERP-C), consisting of a First-Aid team, Evacuation team, Security team, and Message Dissemination team. The Message Dissemination team then relays the message village-wide through various methods, including as word-of-mouth, ringing local temple bells, loudspeaker, and so forth. An in-depth analysis of the ICT equipped first-responders: HIH monitoring staff and ICT-G can be found in [9].

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Message content is encoded using CAP, an open source data interchange standard that includes numerous fields intended to provide consistent and complete messages across different technologies [2]. The implementation of CAP in the LM-HWS is an important aspect of the project because it is key in establishing an "all-media" warning capability.

III. TECHNOLOGY PERFOMANCE INDICATORS

A. *Calculating the Reliability of Alerting Processes*

The basic question governing the reliability measure is "did the ICT based system work on the day of the live-exercise?" Reliability can be measured in at least two aspects: *certainty* and *efficiency*. Whereas certainty refers to the operational state of a device on the day of the exercise and efficiency measures the time taken to complete the transmission of a message in relation to the anticipated hazard risk (i.e., will the message be received with enough advance warning to take action?). The mathematical definitions of certainty and efficiency are described in [10]. The reader may find a similar definition for certainty and reliability in [8] as well. However, the researchers have altered the definition of certainly; where the version in [10] based on signal strength of the technology is the improved and current methodology to assess certainty. The reliability measure is not altered and remains same in both [8] and [10]. This paper uses the definitions from [10] to evaluate the reliability of the AREA in the live exercises. The rating of certainty and efficiency as well as well the combined score; namely the reliability, is on a scale of 0 to 1.

B. *Effectiveness of Terminals in the Last-Mile*

Effectiveness was measured as a function of a set of discrete parameters. The project has defined 11 such discrete parameters: language diversity, full CAP capability, audio and text medium availability, bi-directionality, total cost of ownership, DC power consumption, daily utilization, acknowledgement of message receipt, active alerting functionality, weight of wireless ICT, and volume of terminal device. Once again, the mathematical illustration of the effectiveness measure can be obtained from [10]. The researchers first included signal strength and coverage of the ICT to be an effectiveness measure in [8]. Thereafter, the signal coverage and strength measure was categorized as a certainty measure of reliability rather than an effectiveness measure. Hence, the Effectiveness measures discussed in [10] is the recommended set. The score for each of the parameters as well as the overall score of effectiveness is a real valued ranking ranging from 0 to 1.

IV. COMMON ALERTING PROTOCOL

A major feature of the HazInfo Project employed the use of a standard data interchange known as the "Common Alert Protocol" (CAP) between the message-relay and the end-user technology. The reasons for integrating open source XML-based CAP into the project is mentioned in [1], [2] and [7]. The implantation strategy and construction of the 'CAP Profile for Sri Lanka' is discussed in [2].

"*CAP Message Interoperability*" was subjectively studied by assessing the "action taken" by the message recipient. For this assessment, the CAP message relayed from the HIH and actions taken were recorded by each First-Responder. The effectiveness was measured as to how well the First-Responders could record the message received over the particular device and interpret it. The input of CAP messages to the system and the respective output of the CAP message being displayed on the terminal device are discussed in [7].

V. EXPECTED PERFORMNCE OF THE DEVICE

A. Transmission Technology

There are two types of satellite transponders onboard the WS satellites, one transparent and the other on-board processed. The Transparent Repeater repeats Time Division Multiplexed (TDM) carriers sent to the satellite from large earth stations at X-band onto downlink carriers at L-band. Each satellite has three spot beams with each beam containing two TDM carriers centered at different frequencies in the band 1452-1492 MHz. Each beam covers a large geographical area and with the six beams on the two satellites in service, the coverage extends to more than 130 countries in Asia, Africa and Europe.

Each TDM carries 1.536 Mbps, divided into 96 Prime Rate Channels (PRC) each of 16kbps. A basic audio program can use just one PRC and achieve an audio quality better than analog short wave as WS uses efficient audio coding scheme MPEG Layer-3. As many as 8 PRCs can form one Broadcast Channel (BC) depending on the desired quality. The WS digital format incorporates interleaving, 255, 223 Reed-Solomon block coder and Rate ½ Vitterbi convolution encoding technologies to protect the service against transmission errors. At any given geographical location, typically 30-40 subscribable audio channels are available, giving the listener enough choice.

B. *AREA Terminal Device Components*

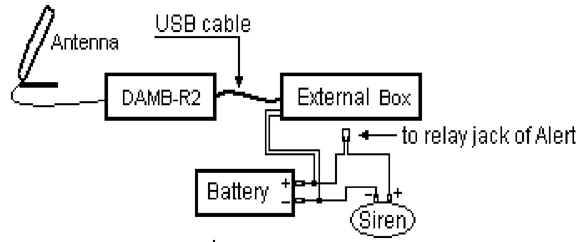

Figure 2: Components of the AREA Terminal device

The receiver, called DAMB-R2, is a low-memory radio with a small display and a limited processing power. DAMB-R2 features dual channel reception with one of the channels designated as a data channel called OAAC (Over Air Activation Channel). Through the OAAC channel the alert provider can send an alert message. DAMB-R2 has the capability to monitor the alert, validate the message and perform the specified action. The action could range from activating a relay for a siren, turning on/switch to a WS channel for audio messages and displaying text regarding the alert.

An external box can be fitted via a USB to the DAMB-R2 to enhance the display with a larger digital display as well as couple other peripherals such as an audible siren and GPS receiver.

A palm-sized linear patch antenna was used to receive the services. All WS specific processing including MPEG decoding is handled by the StarMan chipset, which is incorporated in all the receivers. Each radio receiver features a BC digital output connector allowing to access to the full content of the selected BC from an external appliance.

C. ANNY Network Interface

The uplink segment includes a special, secure, web interface, hosted at one or more of the designated centers from where the Emergency Warning message is generated. Additionally, the interface incorporates procedures for authentication and logging of the alerts, generation, uploading and scheduling of transmission of content for the supplementary audio channel that WS supports once an alert is announced, updating an announced alert, canceling the alert, periodic end-to-end testing of the entire system.

D. Complementing the deficit of Bi-directionality

The research acknowledges that simply issuing the message from the HIH alone is inadequate. The Alerting function is complete if the message is received by the ICT-G and an acknowledgement message is returned via the same or alternate path to the Sender at the HIH Message-Relay. The research team also acknowledged the importance of incorporating "bi-directional" capabilities at the village level so that devices could provide communities with means to inquire of situations and inform local hazards to the Sarvodaya HIH (upstream). The WS system's AREA device is limited to downstream communication. Therefore, this particular equipment was married with one other two-way communication equipment to form an ICT where the coupled configuration: AREA with mobile phone and AREA with nomadic phone would have bi-directional capabilities.

VI. OUTCOME OF THE 'AREA' IN THE FIELD

A. Reliability of transmitting CAP Messages

Initial test results show all devices to take less than 7.2 seconds to push the alert messages to the end user AREA devices. The signal path for the alert message is from the Toulouse server to the Singapore BOC, interfacing with the BC-LAN and inserting the binary coded CAP message into the OAAC channel (BCID 2000) for decoding by the DAMB-R2. As DAMB-R2 was able to receive and interpret the alert message, it appears that the CAP coding, binary conversion, routing to the correct port in Singapore are happening correctly.

In terms of certainty there was no issue in receiving the minimum signal strength 4 of 7 bars to receive text and audio alerts. The WS worked without fail in all of the live-exercises, accept for one case when the antenna was not properly aligned for minimum required signal strength. There was a situation where the CDMA and GSM terrestrial public networks work instructed to be turned off by the Government of Sri Lanka in the North-East conflict areas during militaryy operations. However, the satellite based one-way system was operational and was able to receive alerts during the field trials in these conflict areas. The average certainty of the WS AREA devices ranked to be 0.88 during the field trials.

Efficiency as a function of time was measured from the instant the HIH staff created and issued the CAP message through the ANNY Networks to the moment the message was received, decoded, and recorded by the ICT-G. In order to receive the text of the CAP elements, due to the limited 80 character display, the user has to press one of the control buttons of the terminal device to jump to the next text element. This step-by-step operation of scrolling and recording the text message took 2 - 3 minutes. The HIH staff would spend 7 – 12 minutes, depending on the length of the message to record the audio and upload to the server. Thereafter, the message would be queued broadcasted within a few seconds. The WS system for the first set of live-exercises, with respect to a tsunami alert anticipating a 90 minute period, ranked to have an efficiency of 0.87.

B. Effectiveness of the 'Terminal Device

CAP Complete -- The WS additional 'External Box' could display the entire CAP message. The 'External Box' was not tested in the field (i.e. in the communities). The DAMB-R2 tested in the field could display the CAP elements: <*msgType*>, <*scope*>, <*sender*>, , <*status*>, <*category*>, <*urgency*>, <*severity*>, <*certainty*>, and <*event*>. These elements were adequate to provide the ICT-G with the type of hazard and the priority level but inadequate to carry a complete alert bulletin with full instructions. However, the audio message is capable of carrying the <*description*> element of the CAP message. Both the text and audio components together form the mandatory elements of the CAP Profile for Sri Lanka; as a result score a 0.95 on the ability to carry the necessary and sufficient elements of a CAP message. The English text messages received in the rural English illiterate communities were of no use. Hence, an alternative was when issuing an alert using the ANNY Network the HIH staff would instruct the interface to auto switch the audio channel of the DAMB-R2 to the SarvoTalk (BCID 950) channel; follwed by the HIH staff recording and uploadig an audio (voiced) version of the <*description*> element of the CAP message, which would carry the complete bulletin in the three national languages: Sinahala, Tamil, and English. The scoring method also emphaisesd that the ICT be capable of transmit both audio and text, which gave the AREA a 0.95 score for CAP Compliant (i.e. being CAP Complete).

Two-way – The WS systems being a one-to-multi-point system would score an absolute zero in terms of effectiveness because the research emphasised the importance of tow-way communication in warning systems. Therefore, the research had coupled the AREA units with an alternate two-way device such as a GSM mobile phone or CDMA normadic phone. The ICT-G would use the mobile phone or the normadic phone to communicate with the HIH to notify them of any local hazards (upstream communication), which was not possible using the AREA units. This marriage would increase the effectiveness score in terms of two-way of the AREA with mobile phone or AREA with normadic phone to 0.85.

Adoptability – Total cost of ownership and integration of the system into the community daily life measures the adoptability of the system. The cost of an AREA terminal device is well under USD 80. However, the audio channel is what costs the most. Currently the HazInfo project is paying for the audio channel. Sarvodaya being present in 15,000 villages in Sri Lanka can make it affordable to the communities once the system is implemented in all those villages at which point the per user cost for the Channel subscription fee will be affordable, well under USD 10. A norm in the world of 'public alerting' is that the best alerting device is the one that is 'on' and is 'used' all the time. The content for SarvoTalk (BCID 950) is developed by Sarvodaya. The channel is operational around-the-clock where Sarvodaya broadcasts community-development based content to its CUG member communities. There are a dozen trained youth scattered in the coastal districts. They record content on to simple MP3 player/recorders and email the files or deliver the files burned on CDs to the HIH. The HIH has employed a Media Assistant who edits the content received from the communities and uploads on to the WS SarvoTalk channel. Besides normal weekly programs the HIH also captures special events conducted by Sarvodaya such as workshops and community events that are later broadcast to the communities, which keeps the channel alive.

Miniaturization – The idea of the LM-HWS was to use the system during pre and post disasters; where one aspect of the system is to provide alerts with adequate time for the communities to execute their ERPs to protect themselves from the hazards and the second aspect is after the disaster when the community livelihoods are destroyed the system would communicate with the community during response and recovery stages. Therefore, the terminal devices must be portable. The research assessed Miniaturization in terms of the longevity of DC power consumption, volume of the complete terminal device, and weight of the terminal device (including antenna and battery). The WS AREA system can run on a 12v battery that weighs less than 3kg for 8 hours comfortably. The battery can be recharged using a solar panel. The rating for the AREA unit (excluding the solar panel) based on the fact that the unit must function consecutively for at least 30 hours, must weigh less than 30kg (for a single person to carry comfortably), and has a volume that fits in a small suitcase or backpack, scored 0.68. The score improves to 0.94 when the portable solar panel is included in to the rating, which assumes DC power is available for at least 18 hours (assuming 10 hours powered by solar panel during day time and 8 hours of powered battery during night time). AA batteries are also an option.

Alerting – This is an effectiveness feature equally important as CAP Completeness. The parameters: *Active Alert Function* and *Message Receipt Acknowledgement* are what determine the Alerting effectiveness. The message receipt acknowledgement is different from Two-way or upstream communication. This function is important for the message 'recipients' to notify the message 'sender' the receipt of message [8]. Since WS uses *forward-error-correction* encryption and decryption for audio and text packets it is almost impossible for the ICT-G to receive a mutated or truncated message, provided the uplink and satellite doesn't fail during transmission. The ICT-G would use the spouse terminal device married to the AREA such as the GSM mobile phone or CDMA nomadic phone to acknowledge message receipt. During a crisis situation both the GSM and CDMA networks get congested and the acknowledgement would be delayed. Unlike an SMS controller that would receive a return message upon the user accepting the SMS the WS system does not have a message returned to the server, which the HIH staff could query to check if the messages have been delivered to the end user. Active Alert Function describes the basis of being able to get the attention of the ICT-G. The AREA units have an audible alarm. The research ranks an audible siren higher over a flashing light or a vibration which must me in visible range or attached the ICT-G respectively [8]. Although the AREA has the ability to 'wakeup' (or get the attention) of the ICT-G, it is weak in the message receipt acknowledgement as it must rely on an alternate system. Therefore, the overall effectiveness for Alerting scores a 0.22.

VII. CONCLUSION

Looking at the overall picture, the AREA performed very reliably in part because the footprint of the WS AsiaStar is strong in Sri Lanka. However, the AREA was somewhat less effective than initially anticipated because of limitations of text display and user friendliness issues. However, when considering combined performance of the AREA married with a mobile phone or with a nomadic phone, the high reliability of the AREA device with the two-way terrestrial terminal devices provided what we might term "complimentary redundancy" with the two devices working well together in balancing reliability with effectiveness.

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