Robust Emergency Communications Using TxID Watermark of ATSC DTV System

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***Abstract*— In today's world, having a reliable communication system during emergency situations is of paramount importance to lessen the impact of the disasters. This paper proposes an emergency communication technique which is enabled by ATSC DTV transmitter identification (TxID) watermark signal. Theoretical and simulation results show that ATSC TxID watermark signal can reach a larger coverage area than the 8-VSB DTV signal and hence can be used to enable emergency communication during national disastrous situations. The coverage for this emergency communication system is predicted using popular Hata-Davidson propagation model and coverage maps clearly showing the extended and overlapped coverage for DTV stations in Huron and Stratford area in the province of Ontario, Canada is presented. Comparison with other existing emergency communication systems is carried out and performance matrices such as alerting message error rate, required no. of stations, network reliability etc. are evaluated to assess the robustness of the proposed emergency communication system.**

***Index Terms*— Emergency communication, TxID watermark, coverage analysis, network reliability, interoperability.**

I. INTRODUCTION

In the last few years, the world has seen more disastrous situations than ever caused by various environmental, social and political movements, and even man-made. In the recent history, September 11 attacks in the United States of America (2001), devastating Tsunami in Asia-Pacific (2004), Hurricane Katrina in the United States of America (2005), and cyclone Nargis in Myanmar (2008), only few of many others, remind us the outmost necessity of reliable emergency communication system to lessen the sheer magnitude of the disaster the world has seen. The situation is even worse in remote areas those are not covered by modern communication systems such as land or cellular communications. Therefore, it is extremely important to have an effective emergency communication system to make mass people aware in the advent and during national emergencies, including people living in distant rural areas.

The emergency communications bring several challenging requirements such as greater coverage area, coexistence among different communication systems, robust transmission in harsh communication environment, reliability, fast responding etc. [1]. These technical requirements reveals the fact that the establishment of emergency communication infrastructure is very challenging and rigorous attention is needed on important factors which depend on possible scenarios and warning system. However, the presently deployed various emergency communication systems using different platforms are not able to talk with each other i.e., the problem lies in the sense of interoperability among these platforms [2]. On the other hand, interoperability also raises the question of reliability of the whole network because different platforms are having with different radiabilities. That's why, even if the interoperability is achieved among different platforms which still necessities a substantial amount of research, however the reliability of the thereafter network would be a major concern.

Several ad-hoc based emergency networks such as enhanced communication scheme combining centralized and ad-hoc networks (ECCA) [3], sensor network based emergency communication system [4], integrated cellular and ad-hoc relaying system [5] etc. exist in the literature. The key advantages of these ad-hoc based emergency networks are self-organization, fast reconfiguration etc. However, on top of conventional power constraint and delay problem, due to limited coverage, a large number of communicating nodes are required and hence reliability is a major problem in these networks. On the other hand, infrastructure based emergency networks consist PSTN access network, cellular networks, satellite networks and other broadband communication systems. For example, TErrestrial Trunked RAdio (TERRA) [6], integration of IEEE 802.11 and 3G networks [7], HUGHES broadband satellite communication [8] etc. are able to provide emergency communication during disastrous situations. However, as discussed above, the crucial problem for the infrastructure based emergency communication system is

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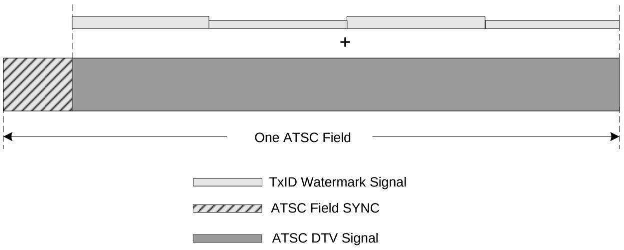

Figure 1. ATSC DTV signal with modulated TxID watermark.

the requirement of a great deal of interoperability among existing communication systems. Although to solve this interoperability issue, measures have been taken through the development of IEEE 802.21 standard body, but they are still under evaluation [9]. However, all the major concerns such as interoperability and reliability are co-related and driven by the limited coverage of existing emergency communication systems.

In this paper, we propose to use TxID watermark signals as the way to send alerting message to the people during emergency situations. The analyses show that modulated TxID watermark signals are more robust than the 8-VSB modulated ATSC DTV signal, leaving us the opportunity to have even extended coverage with that embedded TxID watermark signal. As we are almost at the verge of a fully-fledged DTV broadcasting, therefore this extended coverage ensures that even the people living at the rural distant areas would be able to receive the emergency alerting message before and/or during the disastrous situations. On top of this, as the interoperability is still a far-reach issue, with this proposed technique a greater coverage area is obtained which obviates the interoperability issue along with the higher reliability of the overall network.

The rest of the paper is organized as follows. The proposed emergency communication model along with demodulation of TxID watermark signal and error performance analysis for emergency data is presented in Section II. Section III describes the model for the coverage prediction and coverage analysis for this communication technique is carried out in Section IV. Section V describes the overall reliability of the communication network with comparison to some other existing systems and finally, the paper is summarized in Section VI.

II. EMERGENCY COOMUNICATION SYSTEM MODEL

The proposed emergency communication system in this paper is enabled by existing DTV broadcasting which is growing very fast. The U.S. TV broadcast industry is already at the verge of an all-digital transmission and that in Canada by August 31, 2011 [10]. Virtually, at the end of 2011, North America will have an all-digital DTV broadcasting opportunity and few other countries such as The Netherlands, Finland already made the transition.

The Advanced Television System Committee (ATSC) DTV standards are entirely different from the conventional analog TV signals and have many new features e.g., allowing higher-quality images, sound, and more programming choices etc. [11]. One interesting feature of the ATSC system is that a unique spread spectrum sequence will be assigned for each DTV transmitter as a RF watermark. Since the identification sequence is embedded into original DTV signal as a watermark as shown in Fig. 1 and the strength is very low compared to the original DTV signal, therefore the pseudo-random sequences are long enough so that the peaks obtained from the correlations associated with background DTV noise can be detected.

According to our proposal, these modulated TxID watermark signals will be encoded to send the emergency alerting message to the people during disastrous situations. The proposed transmitter and receiver structure are shown in Fig. 2 and Fig. 3, respectively. The sequence is detected according to the matched filtering approach as discussed in [12]. Once the watermark signal is decoded, the terminal user will be able to get the emergency messages sent form either the government or private authorities. However, we can use existing DTV infrastructure which clearly obviates the need for new infrastructure and thus cost-effective than most other emergency communication systems currently available.

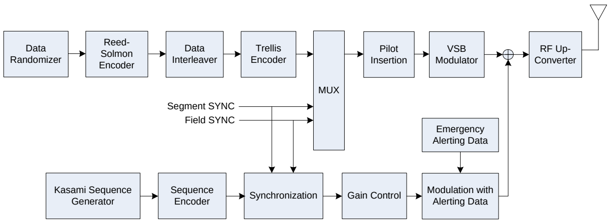

Figure 2. Proposed TxID enabled emergency communication system transmitter.

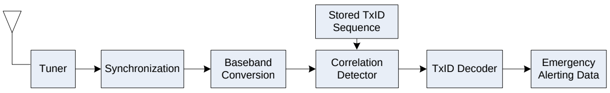

Figure 3. Proposed TxID enabled emergency communication system receiver.

A. TxID Watermark Emergency Data Insertion and Detection Procedure

In this subsection, TxID watermark emergency data insertion into DTV signal and corresponding detection algorithm will be discussed. Let us take the DTV signal for the i-th transmitter before and after the injection of the pseudo random sequence as $x_i(n)$ as $d_i(n)$ and $d'_i(n)$, respectively. Note that each DTV transmitter would have a unique x_i, thus it is always recognizable even within the coverage of other stations. The injection of the transmitter identification sequence into DTV signal being modulated by the emergency alerting data, a_d results

$$d'_i(n) = d_i(n) + \rho x_i(n) a_d(i). \qquad (1)$$

where ρ is a gain coefficient to control the injection level. The injection level of the TxID watermark signal can be different from transmitter to transmitter. However, it will be convenient for the emergency data demodulation process if the gain is set to the the same level for all the transmitters [13]. After passing through channel h_i, the received signal from the i-th transmitter, r_i is

$$r_i(n) = d_i'(n) \otimes h_i + n_i(n). \tag{2}$$

where $n_i(n)$ is the noise at the input of the i-th receiver. The overall received signal, $r(n)$ is then given by,

$$r(n) = \sum_{i=1}^{T} \left[d_i'(n) \otimes h_i + n_i(n)\right]. \tag{3}$$

where T is the total number of DTV transmitters. The TxID watermark signal i.e., the emergency data will be demodulated based on the correlation process. Using this approach, cross-correlation between $r(n)$ and $x_j(n)$ will be evaluated at the receiver side to find out the emergency data from the j-th transmitter as follows,

$$\begin{aligned}
R_{rx_j}(m) &= \sum_{n=0}^{N-1} r(n) x_j(n-m) \\
&= \sum_{n=0}^{N-1} \left\{ \sum_{i=1}^{T} d_i'(n) \otimes h_i + n_i(n) \right\} x_j(n-m) \\
&= \sum_{n=0}^{N-1} \left[\sum_{i=1}^{T} \{d_i(n) + \rho x_i(n) a_d(i)\} \otimes h_i + n_i(n) \right] x_j(n-m) \\
&= \rho a_d R_{x_j x_j} \otimes h_j + \sum_{i=1, i \neq j}^{T} \rho R_{x_i x_j} \otimes h_i \\
&\quad + \sum_{n=0}^{N-1} \sum_{i=1}^{T} \left[d_i(n) \otimes h_i + n_i(n)\right] x_j(n-m).
\end{aligned} \tag{4}$$

where N is the length of the pseudo random sequence $x_j(n)$ which is used as TxID watermark signal. With the orthogonal property of the selected pseudo random sequence, $R_{x_j x_j}$ can be approximated as a delta function. The second and third terms in the above equation are only noise-like sequences from the in-band DTV signals of the same transmitter and the other transmitters. Therefore, the received channel response h_j from the j-th transmitter can be approximated from R_{rx_j} and is given by

$$\begin{aligned}
R_{rx_j}(m) &= A a_d h_j + \text{noise} \\
&= A' h_j + \text{noise}.
\end{aligned} \tag{5}$$

where A is a constant determined by $R_{x_j x_j}$ and the gain coefficient ρ. The received channel response h_j from the j-th transmitter can be determined as $R_{x_j x_j}$ and ρ are known. Then the decision about a particular TxID enabled emergency signal, a_d can be determined based on the correlation output obtained in (5).

In the subsequent sections, the analysis will be carried out in the assumption of an AWGN channel. As the TxID watermark signal is long enough and most of the times DTV antenna stature will be higher than that of the average terrain or obstacle height, thus it is reasonably a valid assumption.

B. Error Rate Analysis for Emergency Data

Let us consider, the correlation peak is denoted as $A + n_1$, where A is the auto-correlation peak of a TxID emergency sequence and n_1 is the associated interference for that autocorrelation function at first sample instant. When a TxID emergency sequence of N samples is used, ideally the autocorrelation peak will be N. If TxID has a total of M watermark signals, for the rest of $M-1$ cross-correlation functions at first sample instant, $B_c + n_2$ will take values centered on the following discrete levels [14]

$$\{-t(n),\ -s(n),\ -1,\ s(n)-2,\ t(n)-2\},$$

where $t(n) = 1 + 2^{\frac{n+2}{2}}$, and $s(n) = \frac{1}{2}\left[t(n)+1\right]$. n_2 is the interference for the cross-correlation function at first sample instant. Both n_1 and n_2 are considered Gaussian distributed since they are the summations of sufficiently long interference samples as a result of the autocorrelation and cross-correlations. However, the correct demodulation of the TxID encoded emergency data sequence in the presence of one cross-correlation function with a peak of $B_c + n_2$ should meet the criteria $A - B_c > n_1 + n_2$. Consider the following probability density function of a new random variable $Y > n_1 + n_2$ for the evaluation of probability of making false detection

$$\begin{aligned}
f_Y(y) &= \int_{-\infty}^{\infty} f_{N_1}(n_1) f_{N_2}(y-n_1) dn_1 \\
&= \int_{-\infty}^{\infty} \frac{1}{\sigma_n\sqrt{2\pi}} e^{-\frac{n_1^2}{2\sigma_n^2}} \frac{1}{\sigma_n\sqrt{2\pi}} e^{-\frac{(y-n_1)^2}{2\sigma_n^2}} dn_1 \\
&= \frac{1}{\sigma_n\sqrt{2\pi}} e^{-\frac{y^2}{2\sigma_n^2}} \int_{-\infty}^{\infty} \frac{1}{\sigma_n\sqrt{2\pi}} e^{-\frac{2(n_1-y/2)^2-y^2/2}{2\sigma_n^2}} dn_1 \\
&= \frac{1}{2\sigma_n\sqrt{\pi}} e^{-\frac{y^2}{4\sigma_n^2}}.
\end{aligned} \tag{6}$$

where σ_n is the standard daviation of the noise from dominant in-band DTV signal and AWGN, given by

$$\sigma_n^2 = N(\sigma_{DTV}^2 + \sigma_{AWGN}^2). \tag{7}$$

Thus the Probability of getting an erroneous decision in presence of one correlation is given as follows,

$$\begin{aligned}
P_{e,c}(n_1 + n_2 > A - B_c) &= \int_{A-B_c}^{\infty} \frac{1}{2\sigma_n\sqrt{\pi}} e^{-\frac{y^2}{4\sigma_n^2}} dy \\
&= \sqrt{2}\sigma_n \int_{\frac{A-B_c}{\sqrt{2}\sigma_n}}^{\infty} \frac{1}{2\sigma_n\sqrt{\pi}} e^{-\frac{z^2}{2}} dz \\
&\qquad [\text{Taking } z = \tfrac{y}{\sqrt{2}\sigma_n}] \\
&= \frac{1}{\sqrt{2\pi}} \int_{\frac{A-B_c}{\sqrt{2}\sigma_n}}^{\infty} e^{-\frac{z^2}{2}} dz \\
&= Q\left(\frac{A-B_c}{\sqrt{2}\sigma_n}\right).
\end{aligned} \tag{8}$$

Letting $\beta = (\frac{A-B_c}{\sqrt{2}\sigma_n})$, (8) can be further simplified as

$$\begin{aligned}
P_{e,c}(n_1 + n_2 > A - B_c) &= Q(\beta) \\
&= \frac{1}{2} - \frac{1}{2} erf(\frac{\beta}{\sqrt{2}}).
\end{aligned} \tag{9}$$

As the sequence length is very long, thus it is quite impossible to find out the exact occurrence of different correlation peaks. Therefore, in our analysis, we assume that the occurrence probability for five different correlation peaks are equal. So, the average probability that the decision is false in presence of one correlation over N correlation samples is given by,

$$P_e = \frac{1}{N}\sum_{c=1}^{5} P_{e,c}(n_1 + n_2 > A - B_c). \tag{10}$$

The corresponding probability of getting a correct decision over N correlation samples can be written as

$$\overline{P}_e = 1 - P_e. \tag{11}$$

Therefore, probability of making false detection in presence of $M^{'}$ sequences is given by,

$$\begin{aligned} P_{et} &= [1 - \overline{P}_e^{M^{'}-1}] \\ &= [1 - (1 - P_e)^{M^{'}-1}]. \end{aligned} \tag{12}$$

where $M^{'}$ is the number of sequences compared in the demodulation procedure and $M^{'} \leq M$. Fig. 4 shows the theoretical error rate for emergency alerting data while varying total number of sequences those are compared in the correlation process and number of sequence modulated. It is seen that as the number of sequences compared are increased, the error rate is also increased, but it is not proportional. Thus it is expected that when larger number of sequences will be compared, the increase in error rate will be insignificant.

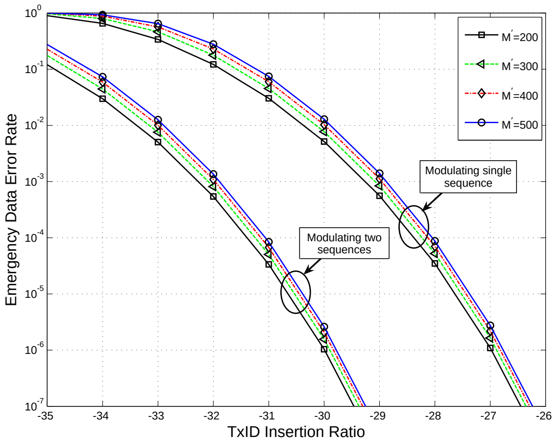

Figure 4. Theoretical error rate for emergency alerting data.

C. Performance Evaluation Criteria

According to the ATSC DTV standard, the reliable reception of DTV signal at the terminal user requires a carrier to noise (C/N) ratio of 15dB [15] at the threshold of visibility (TOV) which is assumed as BER $= 3 \times 10^{-6}$. However, in our comparison with other systems, we have considered signal to noise ratio (SNR) as the reference parameter. It is well known that in DTV transmission a pilot is added at 310KHz frequency to facilitate the synchronization issue [11]. Thus to find the equivalent SNR of that C/N ratio, we need to determine the power carried by the pilot.

If we take R_s as the symbol rate for DTV transmission, then the Average signal power in a 8-VSB system is $21R_s$ [11]. Thus for a single pulse the energy is, $E_s = 21$. A DC offset, $a = 1.25$V is added to the 8-VSB signal to generate the pilot tone. Therefore, the ratio of pilot power to the average signal power is $r = \frac{a^2}{E_s} \approx 7.44\%$. Hence, the SNR for 8-VSB signal can be written as,

$$\begin{aligned} \text{SNR} &= C/N - 10\log a^2 \\ &= 13.061 \text{ dB}. \end{aligned} \tag{13}$$

It is known that one complete ATSC DTV field contains 259584 symbols. Hence if the TxID watermark is injected 30dB below the DTV signal, the equivalent signal to interference ratio (SIR) is then $10\log(259584) - 30 = 24.14$dB and for a BPSK modulated system this corresponds to a BER $\approx 10^{-68}$. But our requirement is much less than that, only BER $= 3 \times 10^{-6}$. Similarly, for a BER $= 3 \times 10^{-8}$, total noise and interference power can be 12dB above the DTV signal. In other words, for our BER at TOV, it is found from Fig. 4 that TxID watermark can be almost 27dB more robust than the DTV signal when only one sequence is modulated and even more while two sequences are modulated, giving the insight that it can be used to cover a larger area than the DTV signal. In this paper, we have made use of this key concept to enable emergency communication using TxID watermark signal.

III. COVERAGE PREDICTION

Our next step is to analyze the coverage for the proposed emergency communication technique. To predict the coverage for the proposed technique, we have considered Hata-Davidson model which is an extension of Okumura-Hata model [16] with some flexibilities in the range of propagation distance, antenna height at the base station with a broader frequency range [17]. The range of input parameters for Hata-Davidson model are shown in Table I.

According to the Hata propagation model, the loss in dB scale is given by,

$$\begin{aligned} L_{Hata} =& 69.55 + 26.16\log f_{MHz} - 13.82h_1 - l(h_2) \\ &+ (44.9 - 6.55\log h_1)\log d_{km} - K \end{aligned} \tag{14}$$

where the parameters $l(h_2)$ and K depends on the type of area as tabulated in Table II.

Then the Hata-Davidson propagation loss follows [17]

$$\begin{aligned} L_{HD} =& L_{Hata} + L(h_1, d_{km}) - S_1(d_{km}) - S_2(h_1, d_{km}) \\ &- S_3(f_{MHz}) - S_4(f_{MHz}, d_{km}) \end{aligned} \tag{15}$$

TABLE I. Range of input parameters for Hata-Davidson model

Frequency range, f_{MHz}	30-1500MHz
Base station antenna height, h_1	20-2500m
Receiving station antenna height, h_2	1-10m
Propagation distance, d_{km}	1-300km

TABLE II. Area dependent parameters for Hata-Davidson model

Type of area	$l(h_2)$	k
Open	$(1.1 \log f_{MHz} - 0.7)h_2 - (1.56 \log f_{MHz} - 0.8)$	$4.78(\log f_{MHz})^2 - 18.33 \log f_{MHz} + 40.94$
Suburban		$2[\log(f_{MHz/28})]^2 + 5.4$
Medium-small city		0

TABLE III. Propagation distance dependent parameters for Hata-Davidson model

Distance	$L(h_2, d_{km})$	$S_1(d_{km})$
$d_{km} < 20$	0	0
$20 \leq d_{km} < 64.38$	$0.62137(d_{km} - 20)[0.5 + 0.15 \log(h_1/121.92)]$	0
$64.38 \leq d_{km} < 300$	$0.62137(d_{km} - 20)[0.5 + 0.15 \log(h_1/121.92)]$	$0.174(d_{km} - 64.38)$

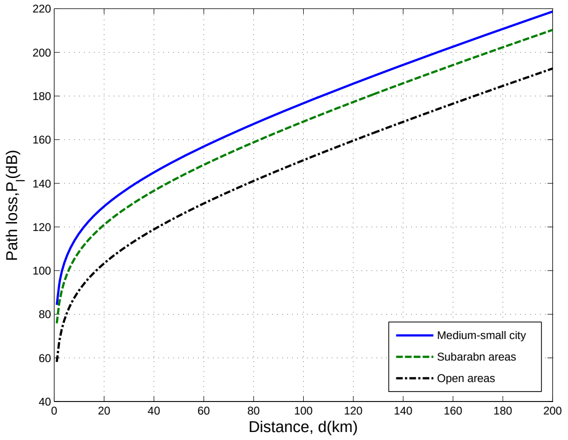

Figure 5. Propagation path loss using Hata-Davidson model in different type of areas.

where L and S_1 are distance correction factors extending the range to 300km and is shown in Table III.

The other factors such as $S_2(h_1, d_{km})$ is the base station antenna height correction factor, $S_3(f_{MHz})$ and $S_4(f_{MHz}, d_{km})$ are frequency correction factors which are not used in our analysis. The path loss, according to Hata-Davidson model for different type of areas is shown in Fig. 5.

To analyze the coverage, we have considered a DTV station in South Huron (near London), ON, Canada area with the parameters obtained from DTV allotment table provided by industry Canada and shown in Table IV [18]. Please note that as the suburban areas in Tokyo generally reflects the propagation characteristics of North American's typical urban areas [16], thus in our coverage analysis we have considered South Huron, Canada as a suburban area for this propagation loss modeling.

Once the path loss is known, the received power is determined by

$$P_r(\text{dBm}) = P_T(\text{dBm}) - L_{HD}(\text{dB}). \tag{16}$$

And shown in Fig. 6 for a DTV station mentioned above. As our analysis is based on the SNR of received signal, thus to obtain that variation of SNR with distance, we need to know the corresponding noise power. The well-known noise model to determine the noise in the TV bandwidth is given by [11],

$$N = -174 + 10 \log(\Delta f). \tag{17}$$

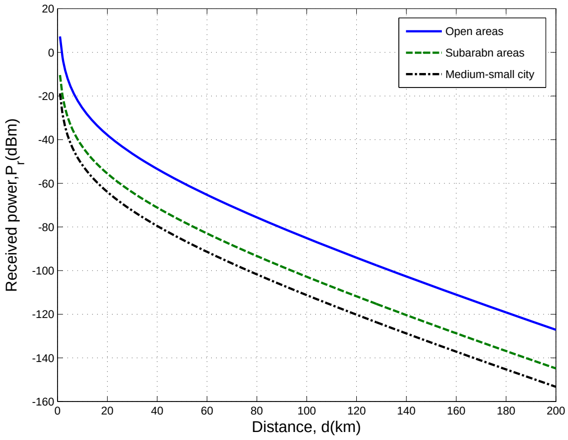

Figure 6. Received power for a DTV station at South Huron area near London, ON, Canada with a transmitter power of 3.5kw.

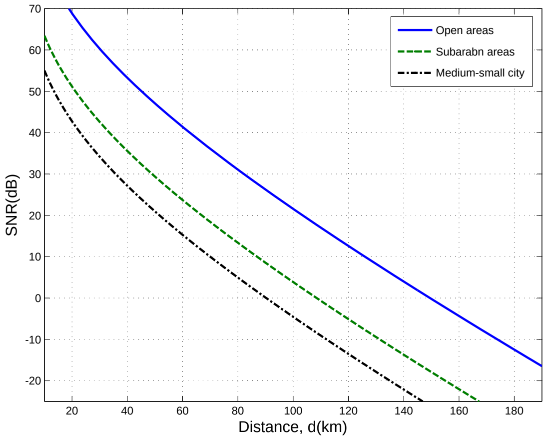

Figure 7. Variation of SNR with the propagation distance for a DTV station at South Huron area.

where N is the noise power and Δf is the effective TV bandwidth which equals 5.38MHz and hence noise power becomes -106.7dBm. The corresponding variation of noise with respect to distance for that DTV station is shown in Fig. 7.

The coverage is then predicted based on the SNR requirement for the system as discussed in subsection II-C. It is seen from Fig. 7 that for the DTV station at South Huron, the 8-VSB DTV coverage at 13.061dB maintaining TOV is ≈81km. On the other hand, as the modulated TxID is found to be at least 27dB more

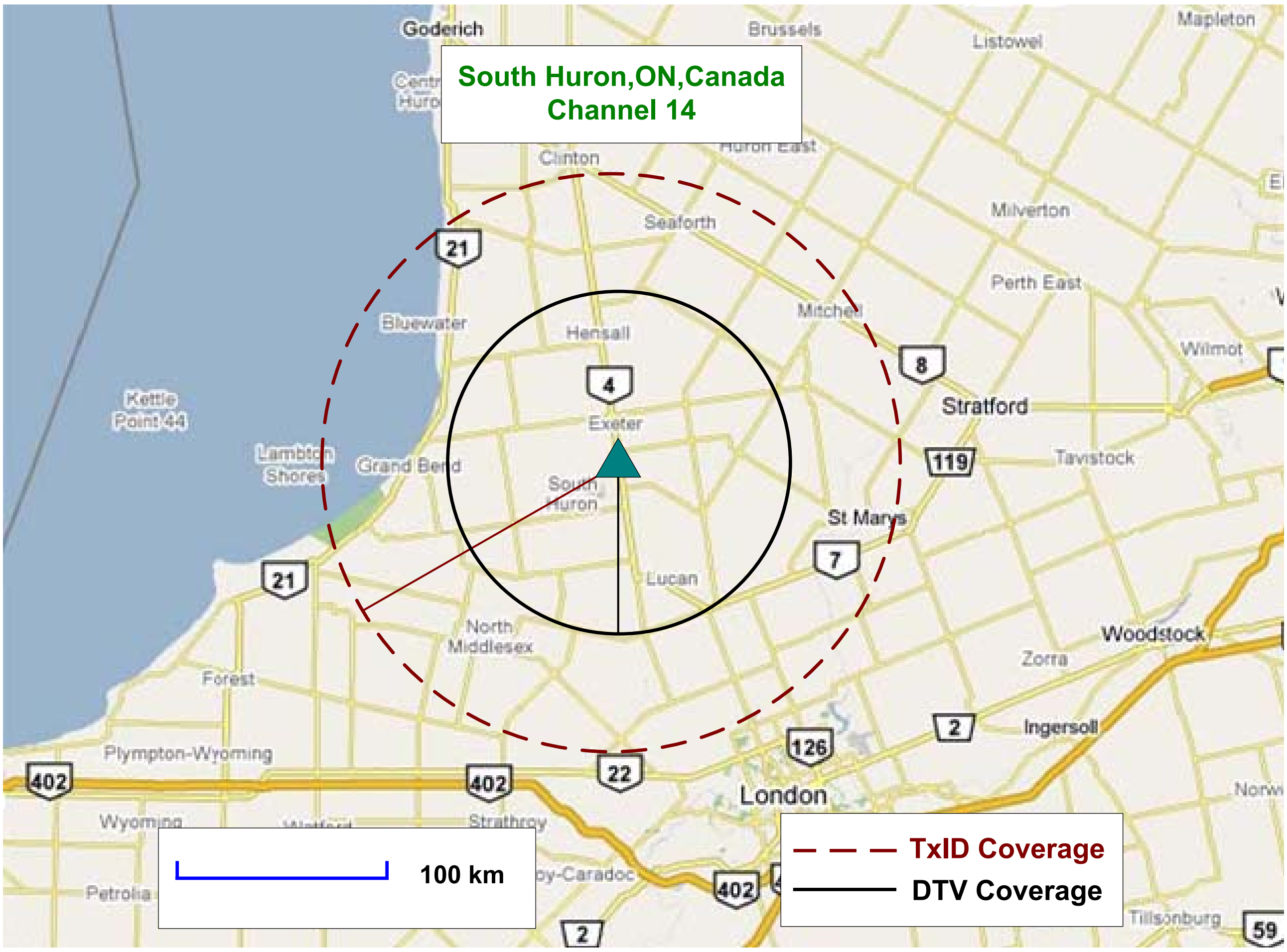

Figure 8. Extended emergency coverage obtained using modulated TxID watermark signal at South Huron area.

robust than the DTV signal i.e. requirement of SNR for maintaining TOV is now about -13.94dB, therefore it could be reached as far as ≈141km, providing the extended coverage for emergency communication.

IV. COVERAGE ANALYSIS

By the virtue of TxID watermark signal enabled emergency communication, basically we have obtained two fold advantages. The first advantage is that it can provide extended coverage as discussed in previous section. Next it is found that it can also provide overlapped coverage with other stations without bringing any extra cost. The eventual advantage obtained by the overlapped coverage is that even if one station fails during disastrous situation, the nearby station will be able to provide emergency service to a considerable coverage of that failed station which is indeed very important in emergency situation.

At first, we have considered South Huron near London city, Ontario to show the extended coverage. Fig. 8 shows the extended coverage obtained by this proposed emergency communication technique with respect to the DTV coverage as discussed in Section III. It is also obvious from this map that an appreciable extended coverage, about 60km is obtained using TxID watermark signal.

TABLE IV. Parameters for DTV station at South Huron area

Channel	14
Frequency, f_{MHz}	473MHz
DTV station antenna height, h_1	197.6m
TV antenna height, h_2 (assumed)	9.2m
DTV transmitter power, P_T	3.5kw

Next we have considered another region namely, Stratford nearby London city to show the overlapped coverage with that station. The parameters for this DTV station is shown in Table V [18]. Similarly, it is found that maintaining TOV at the required SNR, the DTV coverage is ≈44km whereas that of TxID emergency coverage is ≈99km. From Fig. 9 it is obvious that with the assigned transmission power they marginally overlap each other in terms of DTV coverage but largely overlap each other when the TxID coverage is considered.

According to the report published by United Nations, currently more than three billion people are living in rural areas [19]. On the other hand, the quality of services offered by existing communication systems in rural areas, characterized by low densities of populations, is well below than that offered by operators in urban and suburban areas [20], [21]. In those cases, TxID enabled extended

TABLE V. Parameters for DTV station at Stratford area

Channel	46
Frequency, f_{MHz}	665MHz
DTV station antenna height, h_1	100m
TV antenna height, h_2 (assumed)	9.2m
DTV transmitter power, P_T	0.3kw

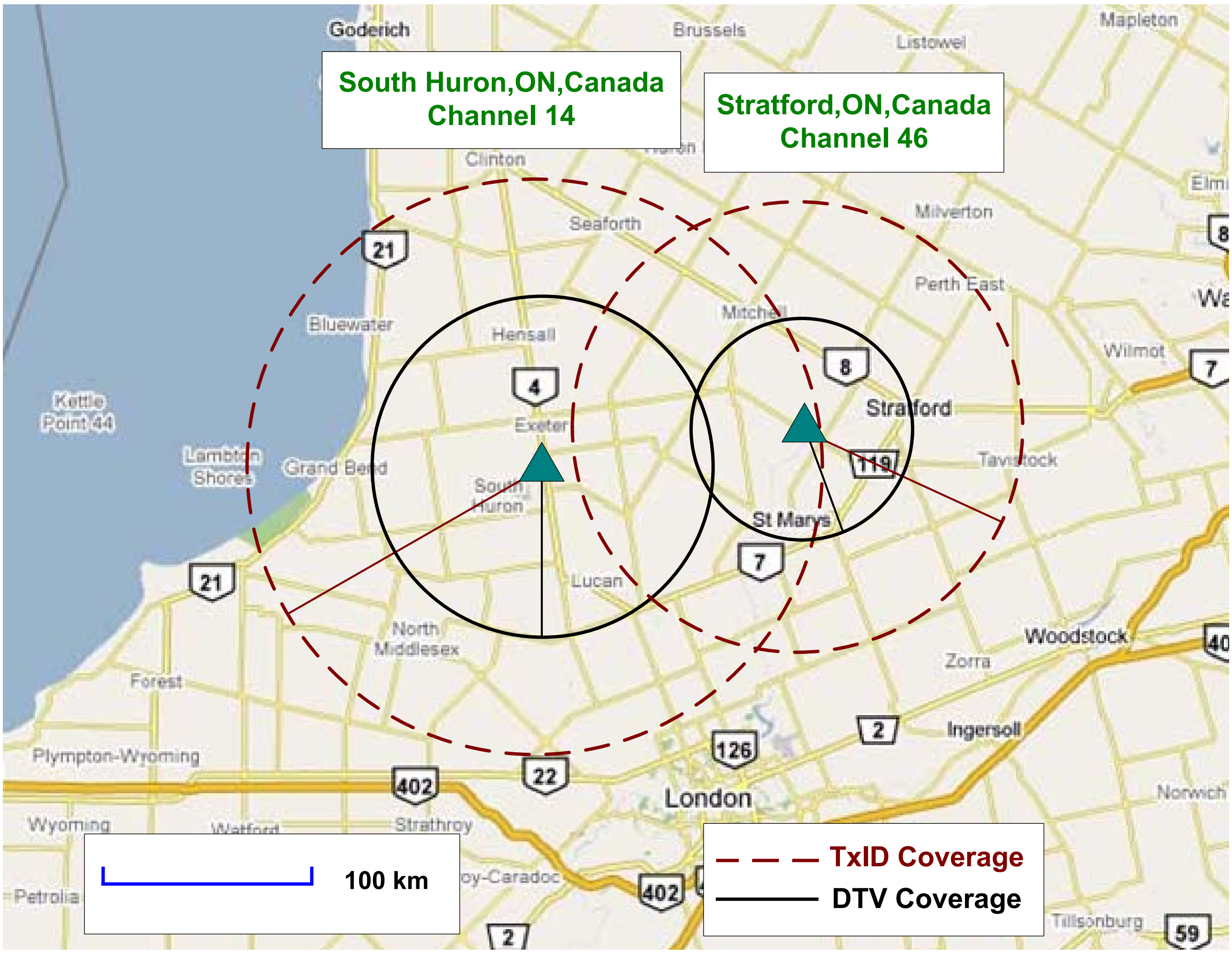

Figure 9. Overlapped emergency coverage obtained using modulated TxID watermark signal at South Huron and Stratford area.

coverage can provide emergency alerting services to rural people which is not generally available from other existing systems due to cost of radio coverage and trunking.

V. NETWORK RELIABILITY

In this section, we will mainly discuss the network reliability along with some other relevant advantages obtained by the proposed emergency communication technique. As discussed above, the first and foremost advantage is the extended coverage than other existing homogenous and/or heterogenous emergency communication technique. As we will be using existing DTV infrastructure, thus the inherent advantages obtained by this technique is the cost-effectiveness. At the same time, other existing systems will require a large number of stations to have the same coverage as TxID enabled emergency coverage. Fig. 10 shows the number of cellular stations required to have typical TxID emergency coverage. It is observed that a large number of cellular stations are required to have TxID equivalent coverage which ultimately brings the concern of network reliability.

To make viable, reliability of any communication network needs to be considered. By definition, reliability is the ability of a network to perform a designated set of functions under certain conditions for a specified period of time [22] and it also depends on the total number of units performing in a communication system. As for the other system to have the same TxID enabled emergency coverage, the required number of nodes/stations in the network would be much larger and therefore weakness in the network infrastructure is inevitable. In our analysis, we have considered a wireless ad-hoc based emergency communication system for comparison purpose. Let T be a random variable representing lifetime of a communication node, then for any specified time t, reliability $R(t)$ and unreliability $F(t)$ can be defined as

$$R(t) = P(T > t), \quad t \geq 0 \tag{18}$$

and

$$F(t) = P(T \leq t) = 1 - R(t), \quad t \geq 0 \tag{19}$$

where $P(T > t)$ denotes the probability that communicating node performs the designated task for the specified time t. To have the same coverage as the proposed TxID enabled communication technique, total number of ad-hoc nodes can easily be determined using similar approach shown in Fig. 10. However, not all the nodes are connected in a particular communication process. A few of them are active to send the collected data to the destination while the others are inactive. Let's take

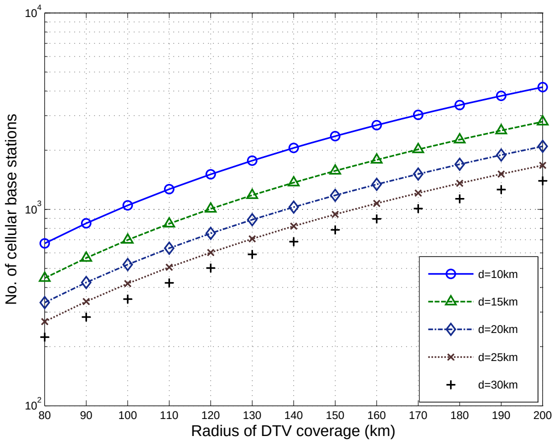

Figure 10. No. of cellular stations required for typical TxID equivalent emergency coverage.

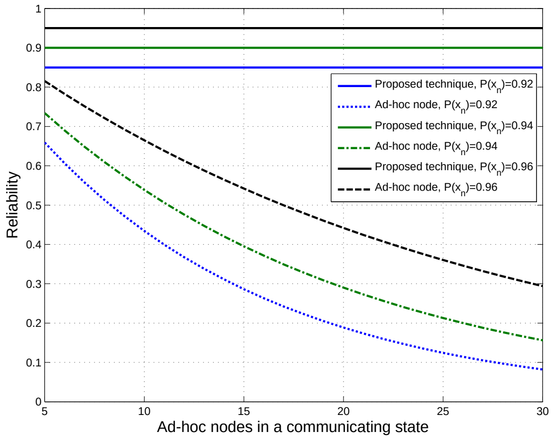

Figure 11. Comparison of reliability between wireless ad-hoc based and proposed emergency communication technique.

there are N nodes involved in a certain communication state, ℓ and $P(x_n)$ denotes the probability of successful communication between nodes. If the nodes are randomly distributed, the reliability for this state is given by [23],

$$\begin{aligned} R_\ell &= P(x_1, x_2, \ldots, x_N) \\ &= P(x_1)P(x_2|x_1)\ldots P(x_N|x_1, x_2, \ldots, x_{N-1}) \quad (20) \end{aligned}$$

However, if the nodes are independent of each other, then the reliability for state ℓ is as follows,

$$R_\ell = P(x_1)P(x_2)\ldots P(x_N). \quad (21)$$

Again, if there is a total of L states within the specified time, the overall network reliability is

$$R = \prod_{\ell=1}^{L} R_\ell. \quad (22)$$

But for TxID enabled emergency communication system, most of the times very few, one or two stations are involved. Hence even with the same probability of success, the reliability of the proposed emergency communication system would be much higher than that of the ad-hoc based emergency network.

Fig. 11 shows the comparison of reliability between proposed technique and wireless ad-hoc based emergency communication system. Here, $P(x_n)$ indicates the probability of successful communication which is assumed equal for both ad-hoc nodes and DTV station. We have also assumed that one DTV station is involved in the emergency communication. Similarly, comparison of reliability with other communication system such as IEEE 802.16 wireless mesh network considering fading model can be assessed using similar approach in [24]. However, network reliability also depends on the physical strength of the telecommunication tower [25]. As the DTV transmitter uses a much stronger tower, it will be less vulnerable to disastrous situations than most other existing techniques which makes the system even more viable in emergency situations.

VI. CONCLUSION

Today's turbulent world sees many emergency situations ranging from natural disasters to terrorist attacks. In this paper, we have proposed an ATSC DTV TxID watermark signal enabled emergency communication technique and corresponding emergency alerting transmitter and receiver structure is presented as well. It is found form the coverage analysis that proposed technique can provide a much larger coverage than other existing emergency communication systems. Again, with the overlapped coverage among DTV stations, it is now possible to send the emergency alerting data to the people living in outskirts, even in rural areas. Beside this, alerting data demodulation technique is discussed and corresponding theoretical error rate analysis for emergency data is carried out. Finally, performance of the proposed technique is evaluated in terms of communicating station/node requirement, network reliability and shown to have improved performance than other existing emergency communication systems.

REFERENCES

[1] L. M. Gavrilovska and V. M. Atanasovski, "Enabling communications in emergency scenarios," in *Proc. Int. Conf. on Telecommun. in Modern Satellite, Cable and Broadcasting Services*, Sep. 2007.

[2] K. D. Stepahn, "We've got to talk: Emergency communications and engineering ethics," *IEEE Tech. and Society Magazine*, vol. 26, no. 3, Fall 2007.

[3] T. Fujiwara, N. Iida, and T. Watanbe, "An ad-hoc routing protocol in hybrid wireless networks for emergency communications," in *Proc. 24th Int. Conf. on Distributed Computing Systems*, March 2004.

[4] T. Fujiwara, H. Makie, and T. Watanbe, "A framework for data collection system with sensor netwoks in disaster communications," in *Proc. Int. workshop on Wireless Ad-Hoc Networks*, 2004.

[5] H. Wu, C. Quiao, and O. Tonguz, "Integrated cellular and ad-hoc relaying system: iCAR," *IEEE Journal on Selected Areas in Commun.*, vol. 19, no. 10, Oct. 2001.

[6] Terrestrial Trunked Radio-TETRA,
URL: http://www.tetramou.com.

[7] M. Buddhikot, G. Chrandramenon, S. Han, Y. W. Lee, S. Miller, and L. Salgarelli, "Integration of 802.11 and third-genration wireless data networks," in *Proc. IEEE INFOCOM*, 2003.

[8] HUGHES Network Systems, "The new age of satellite communications: Meeting the 21st century business needs of the government with satellite broadband solutions," *white paper*, Oct. 2003.

[9] IEEE 802.21: Media Independent Handover, URL: http://www.ieee802.org/21

[10] Federal Communication Commission (FCC), URL: http://www.fcc.gov

[11] J. Arnold, M. Frater, and M. Pickering, "Digital television: Technology and satndard," *John Wiley & Sons.*, 2007.

[12] A. G. Burr, "Capacity improvement of CDMA system using M-ary code shift keying," in *Proc. IEEE sixth Int. Conf. on Mobile Radio and Personal Communications*, Dec. 1991.

[13] X. Wang, Y. Wu, and B. caron "Transmitter identification using embedded pseudo random sequences," *IEEE Trans. on Broadcasting*, vol. 50, no. 3, Sep. 2004.

[14] D. V. Sarwate and M. B. Pursley, "Cross correlation properties of pseudorandom and related sequences," in *Proc. IEEE*, vol. 68, no. 5, pp. 593-619, May 1980.

[15] O. Bendov, J. F. Browne, C. Rhodes, and Y. Wu, "DTV coverage and service prediction, measurement and performance indices," *IEEE Trans. on Broadcasting*, vol. 47, no. 3, Sep. 2001.

[16] G. L. Stüber, "Principles of mobile communication," 2nd Edition, Kluwer Academic Publisher, 2001.

[17] Telecommunication Industry association (TIA), URL: http://www.antd.nist.gov/wctg/manet/docs/TIAWG88_20.pdf

[18] SMBR-005-08-FCC to IC letter at Dec. 2008, Letter of understanding between FCC and Industry Canada (IC), URL: http://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/SMBR-005-08-FCC_to_IC_letter_Dec08_e.pdf

[19] Dept. of Economics and Social Affairs, "World urbinization prospects: The 2005 revision," Oct. 2006. URL: http://www.un.org/esa/population/publications

[20] I. Güvenc, U. C. Kozat, M.-R. Jeong, F. Watanbe, and C.-C. Chong, "Reliable multicast and broadcast services in relay-based emergency communications," *IEEE Journal on Wireless Commun.*, vol. 15, no. 3, June 2008.

[21] M. Pipattanasomporn and S. Rahman, "Information and communication technology infrastructure and its distributed generation solutions in remote areas," in *Proc. Int. Conf. on Elec. and Com. Engg. (ICECE)*, Dec. 2002.

[22] A. P. Snow, U. Varshney, and A. D. Malloy, "Reliabilty and survivabilty of wireless and mobile networks," *IEEE Computer*, vol. 33, no. 7, June 2000.

[23] M. G. H. Bell and Y. Iida, "Network reliability: Experiments with a symbolic algebra environment," Pergamon publisher, 2003.

[24] S. Dominick, N. Bayer, J. Habermann, V. Rakocevic, and B. Xu, "Reliabilty analysis of IEEE 802.16 meah networks," in *Proc. IEEE/IFIP Int. Broadband Convergence Networks*, pp. 1-12, May 2007.

[25] K. El-Fashny, L. E. Chouinard Bayer, and G. McClure, "Reliabilty analysis of a telecommunicatior tower," *Can. J. of Civil Engg.*, vol. 26, no. 1, pp. 1-12, 1999.

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