

Transmission of Disaster Warnings via Control Channels in Cellular Networks

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Abstract—According to United Nations reports, natural disasters caused, worldwide, approximately 100,000 deaths and affected 175 million people each year between 2004 and 2013. To reduce those numbers, countries around the globe have made specific arrangements enabling them to warn the population about imminent disasters, in order to evacuate the area in due time. But providing such warnings in areas where no Internet access is available poses a great challenge. In this paper, we proposed a method to transmit early warning messages via UMTS cellular networks, while relying on spare extensions of control channels (FACH). The results obtained are validate based on their comparison with theoretical considerations and are also benchmarked against the 3GPP standard. The results show that messages may be sent faster than with the use of the 3GPP standard.

Keywords—control channel, disaster reduction, early warning message, mobile network.

1. Introduction

According to reports drawn up by the United Nations (UN), more than 6,873 natural disasters were recorded worldwide between 1994 and 2013, with more than 68,000 lives lost each year, and with the average number of injuries equaling approximately 180 million. 218 million people were affected by such geophysical disasters as, volcanic eruptions, landslides, tsunamis and earthquakes [1].

Humans become increasingly vulnerable to natural disasters due to a variety of factors, such as environmental changes and population growth. Countries around the world have recognized the importance of disaster warnings systems, being a part of their risk management schemes [2]. Accurate weather forecasts and early warning systems are an integral part of disaster prevention solutions which help reduce the losses suffered [1], [3]. However, in some cases, especially in the rural areas, forecasts cannot be reliable if provided for periods over 12 hours [4].

Specific attempts have been made around the world to define adopt an approach that allows to prevent or limit the

aftermath of natural disasters and their impact on human's life. "2030 agenda for sustainable development" adopted in New York in 2015 may serve as a good example here. The meeting at which it was adopted redefined the importance of local level activities and determined goals that need to be achieved in order to make cities inclusive, safe, resilient and sustainable by the year 2030 [5]. Another meeting, held in Paris in 2015 and devoted to climate change, suggested that third-party stakeholders are welcome to participate in addressing the issue and helping reduce the outcomes of natural disasters [5].

The "Sendai framework for disaster risk reduction 2015–2030", first set up in Japan, was adopted by the UN in 2015 at the "Third UN World Conference on Disaster Risk Reduction". It is the first major agreement focusing on the 2030 development agenda and aims to reduce the risk of disasters and to limit losses in human lives. The agenda has set many targets to be achieved by 2030, such as Target G, stating that information warning about disasters should reach all people, regardless of their location [6], [7]. Such an early warning will reduce the outcomes of disasters, provided that the population is evacuated after receiving such an early alert [8].

The messages sent out may be useful even after the occurrence of a hazardous event, providing after disaster support, e.g. by making blood donation requests [8], [9] and shelter locations [10]. The importance of early warning systems may be even greater if they are combined with IT solutions [11]. However, the Internet connection may not be available or reliable outside of cities, which means that other solutions are required [12].

The Internet connection may be overloaded in areas where large numbers of users are present, e.g. in stadiums or concert halls. The speed of the connection and its availability in rural areas are worse than in large cities [13]–[15]. Therefore, importance of early warning messages is even greater in areas where the quality of Internet connections is poor. According to Human Rights Watch, Internet access is blocked in some countries during crisis situations or rev-

olutions, e.g. in Bangladesh, the Democratic Republic of Congo, Egypt, India, Indonesia, Iran, Iraq, Sudan, Myanmar and Zimbabwe [16]. This makes non-Internet solutions even more important.

According to OpenSignal and the GSM Alliance (GSMA), i.e. companies providing statistical data concerning mobile coverage, 3G mobile coverage is better compared with 2G. A study shows that in 95 countries participating in the survey, 93 offered better availability of 3G signal [17], [18]. 3G networks are available worldwide and deployed by 314 operators in 118 countries [19]. While there are some countries and operators planning to switch off 3G before 2G, other states will do the opposite and will shut down their 2G networks before 3G. Some of them have already shut down their 2G networks, e.g. Japan [20], Indonesia [21], [22], Australia [23], South Korea [24], Singapore [25], Taiwan and Thailand [18]. In some countries, operators' policies differ—some of the service providers have already switched off their 2G networks, e.g. AT&T and Verizon in the USA, Telus and Bell in Canada or Swisscom in Switzerland [26]–[29].

The majority of Central and Northern African countries, as well as South-West Asia states are still using 3G and 2G [30], and some of their operators will terminate 2G before 3G, e.g. STC in Saudi Arabia [31] and Vodacom in South Africa [32]. Other countries will follow this trend and will shut down their 2G networks, keeping 3G operational—e.g. the Netherlands [33].

There is no solution that fits all generations of cellular network solutions and that is able to send messages associated with natural disasters. This stems from the fact that the technologies used differ in so many aspects. In this paper, as an alternative to the common SMS system, we propose another method to ensure delivery of messages, because as long as the network works fine, signaling messages such as RACH and FACH will be able to deliver the alerts, even in rural areas, where the Internet connection is poor. The proposed system is using the spare extension of the FACH control channel, transmitted over the secondary control physical channel (S-CCPCH) [34]. The main contribution of this research project is to provide a method, other than an SMS-based solution, to send disaster warning messages without relying on the Internet.

In UMTS, FACH relies on the third general partnership project (3GPP) standard being a part of the radio resource control (RRC) procedure. The random-access channel (RACH) is used as well. Those two solutions are used together to connect the user's equipment (UE) to the core network [34]. Once RRC connection has been completed, other protocols and procedures commence the transmission of data. In the proposed method, data reaches the user immediately after the RRC connection has been established, without a need for completing another step, as FACH spare extension is used to transfer the warning messages. The rest of the paper is organized as follows. Similar applications and disaster message delivering methods are presented in Section 2. Section 3 provides a brief description of the

channel used in the proposed method. The procedure relied upon by the proposed approach is shown in Section 4. Section 5 analyses the model of the channel. System evaluation and system validation are described in Sections 5, 6 and 7, respectively. Finally, conclusions are presented in Section 8.

2. Related Works

Disaster warning messages have been transmitted based on the digital audio broadcasting (DAB) technology by Hongsheng [35]. DAB was relied upon for a two-way transmission of information (uplink and downlink) within the threatened areas. The messages are transmitted from the transmitter to the receiver by dongles attached to a computer operating at each end. mKRISHI is another warning system that alerts fishermen at sea or on the coast. It uses VHS transmission as the primary communication method. It has a Web-based database that stores the data and then transmits them to individual users [36].

Other researchers use sensors to check the weather conditions and then transmit information using a wireless sensor network (WSN). However, the proposed method uses GPRS to send alerts to the database in the cloud, and then a real-time video stream is sent to the users using the Internet [36]. Another approach uses WSN to collect weather-related information. It is collected by the sink node and then sent to the data center via the Internet, providing the user with disaster information based on a GPRS connection [37]. Similarly, emergency information is sent using a WSN with an ultrasound sensor, to the main system, via the Internet in [38].

In [39], Solmaz proposed a solution where mobile phones are used as sensors to warn people about an upcoming disaster. The sensor nodes (mobile phones) receive messages from the host (sink) which broadcasts the message.

Social media, such as Twitter, also could be useful in warning the population. Many researchers used them transmit alerts, but the Internet still remains the only medium that is used [39], [40]. Other social media and communicators, like WhatsApp, Facebook and Viber, may also be relied upon to request help [41].

3. FACH and S-CCPCH

UMTS-based radio access networks (UTRAN) usually send information and control data to the user using the FACH control channel, transmitting over S-CCPCH. Each S-CCPCH radio frame needs 10 ms to finish and has 15 slots, each containing 2560 chips. The slot size may be $20 \cdot 2^k$ bits, where k could be any integer number from 0 to 6, depending on the spread factor which equals 2^x (x may equal 2 to 8). Figure 1 shows the structure of S-CCPCH [34], while Table 1 gives the characteristics of each slot type.

The figure shows that size of TFCI field may be 0, 2, 4 or 8 bits, while N_{pilot} field may be 0, 8 or 16 bits. The

remaining fields will be used to transmit control-related information [34].

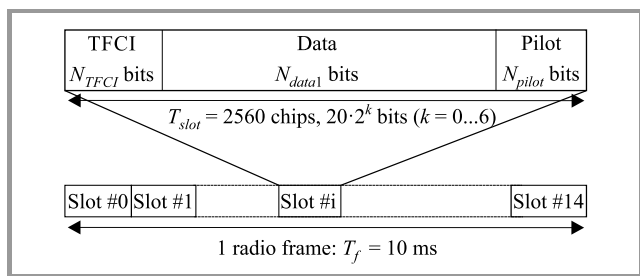


Fig. 1. S-CCPCH radio frame structure.

Table 1
Characteristics of S-CCPCH

SF	Format	Channel bit rate [kb/s]	Channel symbol rate [ks/s]	Bits per slot	Bits per frame
256	0	30	15	20	300
128	4	60	30	40	600
64	8	120	60	80	1200
32	11	240	120	160	2400
16	12	480	240	320	4800
8	15	960	480	640	9600
4	16	1920	960	1280	19200

FACH data will be filled in the slots and then mapped to S-CCPCH fields of the UMTS. If FACH information cannot be fitted into a single slot, the next slot will be used, and then if all slots of the first frame are fully loaded, the next frame will be used.

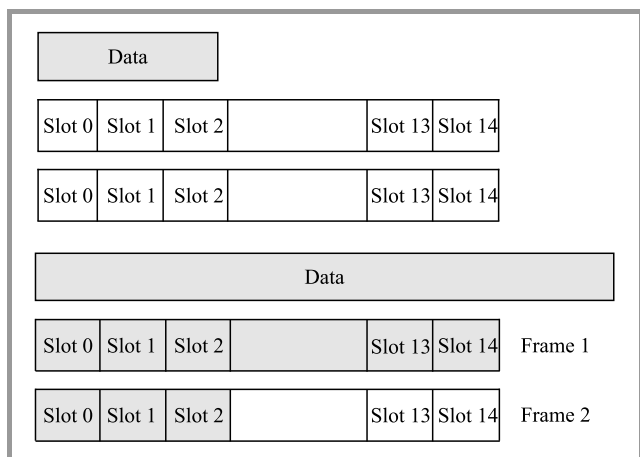


Fig. 2. Mapping data into frames and slots.

4. Proposed Method

The alerts sent may be referred to as downlink, since the warnings are from the mobile network to the UE using UMTS. The universal terrestrial radio access network UTRAN receives the alerts from the operator and a third-

party data and service provider as a part of location-based services [42]. The downlink stage comprises several, as shown in Fig. 3.

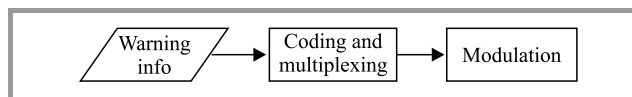


Fig. 3. Downlink steps.

FACH frame may be split into the header and the payload. The header contains such information as field type (FT) and CFN, used to indicate which frame is sent first, and showing the power level (Fig. 4).

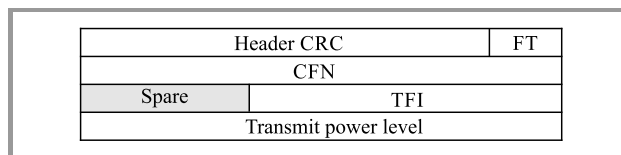


Fig. 4. FACH's header.

The size of the payload is not fixed and may change depending on specific factors, such as spreading and slot format. A change frame size may also be introduced, e.g. the first bit in the new IE FI if it is set, the AOA IE field will be presented and if it is reset the AOA will not be used. In the same way, if the second bit of the new IE FI is active, the LCR ID IE cell portion will be presented [34]. Figure 5 show the payload fields in FACH.

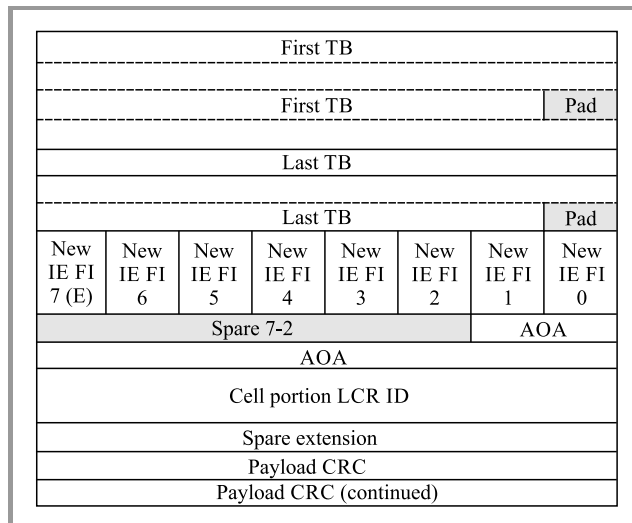


Fig. 5. FACH's payload.

Generally, spare extension fields are filled with zeros, are then transmitted, and the receiver will neglect that data [34]. In the proposed method, the spare extension of FACH is used to transmit the disaster-related message. The FACH frame is then loaded to S-CCPCH. If one slot is not capable of carrying the entire frame, the next slot will be used. Furthermore, if the data cannot be accommodated in one frame, the next frame will be utilized.

The spare extension is 28 8-bits characters in size. If the size of the information needs to be sent is lower, the remaining space of the extension will be filled zeros to reach 28. Yet, if the data size exceeds 28 characters, the second frame will be used. At the end, the CRC sum of the header is calculated and inserted into the header. The CRC value of the payload is also calculated but with a different polynomial to achieve better reliability [34]. Finally, each two-bit piece of data will be presented as one symbol and will be sent using QPSK modulation. Figure 6 shows a flowchart of the downlink process.

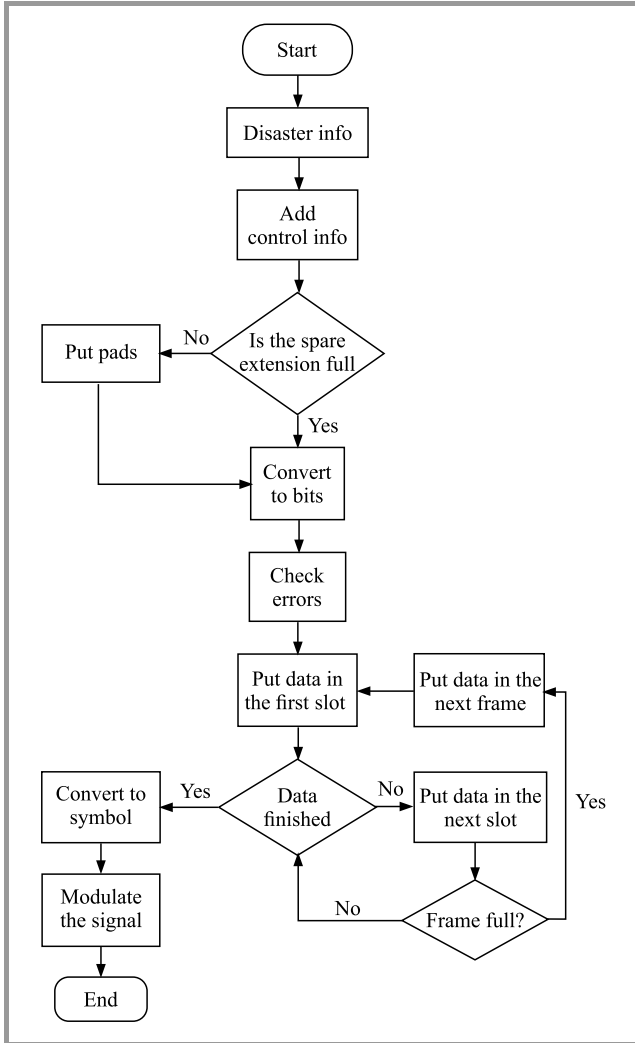


Fig. 6. Sending procedure flowchart.

On the receiver side, the UE extracts the information from the spare extension. The spreading factors of S-CCPCH may assume different values, i.e. 4, 8, 16, 32, 64, 128, and 256.

5. The Model

In this section, the analytical model of the proposed method is presented. First, the S-CCPCH calculation is shown,

which is the same for the proposed method and the 3GPP standard. Then, calculation for FACH for 3GPP standards will be presented and, finally, the FACH model will be shown.

The disaster information is loaded into the spare FACH extension. S-CCPCH carries FACH. Let an S-CCPCH frame be called X and be divided into 15 slots $(y_1 \dots y_{15})$ [43], such as:

$$X = \{y_1, y_2, \dots, y_i\} . \quad (1)$$

Each slot has N_{TFCH} and N_{pilot} and it will be set to 8 as it is the most common slot format [43]. That will leave the size of the slot as:

$$Size_y = 20 \cdot 2^k - N_{TFCH} + N_{pilot} , \quad (2)$$

$$Size_y = 20 \cdot 2^k - 8 , \quad (3)$$

where the k value could be from 0 to 6, depending on the spreading factor SF which could be 4, 8, 16, 32, 64, 128, or 256. Value K may be calculated from:

$$SF = \frac{256}{2^k} \implies k = \frac{\log \frac{256}{SF}}{\log 2} . \quad (4)$$

Because the frame size is equal to the number of slots multiplied by its number (up to 15 slots), then the frame size is:

$$Size_x = \sum_1^m Size_y , \quad m \leq 15 \text{ [bits]} , \quad (5)$$

$$Size_x = \sum_1^m (20 \cdot 2^k) - 8 \text{ [bits]} , \quad (6)$$

where $K \in \{0, 1, 2, 3, 4, 5, 6\}$ and $m \leq 15$,

$$Size_x = \sum_{i=1}^m \left(20 \cdot 2^{\frac{\log \frac{256}{SF}}{\log 2}} \right) - 8 \text{ [bits]} , \quad (7)$$

$SF \in \{4, 8, 16, 32, 64, 128, 256\}$, and $m \leq 15$.

The channel bitrate is:

$$Ch_{bitrate} = \frac{Size_x}{Time} . \quad (8)$$

Because the time needed to finish one frame is 10 ms the channel bitrate will be:

$$Ch_{bitrate} = \frac{1}{10} \cdot \sum_1^m \left(20 \cdot 2^{\frac{\log \frac{256}{SF}}{\log 2}} \right) - 8 \text{ [Kbps]} , \quad (9)$$

for $SF \in \{4, 8, 16, 32, 64, 128, 256\}$, $m \leq 15$.

The data size in FACH needs to be calculated in order to know how many frames S-CCPCH will need in order to send the data loaded into FACH. The FACH structure has two main parts: the header and the payload, where the header size is four bytes [34], and the payload has many fields used for configuration and control. These fields are

5 bytes long. Also, the payload section has transport block fields (TB). Each of them is 8 bits long. The spare extension section will finally comprise 28 bytes.

The size of the spare extension may be up to 28 bytes, and can be calculated from:

$$SE = \left\lceil \frac{DI}{28} \right\rceil \cdot 28 - DI \text{ [bytes]}, \quad (10)$$

where SE is the spare extension size and DI is the disaster information. If DI size is below 28 bytes, SE will add pad fields to empty places. Because the information will be sent in SE , the TB field in FACH will be omitted and the payload size will be:

$$Payload = 5 + SE + DI \text{ [bytes]}, \quad (11)$$

$$Payload = 5 + \left\lceil \frac{DI}{28} \right\rceil \cdot 28 \text{ [bytes]}, \quad (12)$$

where “5” is the number of bytes for the control fields. The number of frames needed without the header can be calculated as:

$$N_{frame} = \left\lceil \frac{Payload}{Size_x - 32} \right\rceil, \quad (13)$$

$$Header_{size} = 4 \cdot N_{frame} \text{ [bytes]}, \quad (14)$$

$$Header_{size} = 8 \cdot 4 \cdot \left\lceil \frac{8 \cdot (5 + \left\lceil \frac{DI}{28} \right\rceil \cdot 28)}{\sum_1^m (20 \cdot 2^{\frac{\log \frac{256}{SF}}{\log 2}} - 8) - 32} \right\rceil, \quad (15)$$

$$Data_{size} = Header_{size} + Payload, \quad (16)$$

$$Data_{size} = 32 \cdot \left\lceil \frac{8 \cdot (5 + \left\lceil \frac{DI}{28} \right\rceil \cdot 28)}{\sum_1^m (20 \cdot 2^{\frac{\log \frac{256}{SF}}{\log 2}} - 8) - 32} \right\rceil + 8 \cdot \left(5 + \left\lceil \frac{DI}{28} \right\rceil \cdot 28 \right). \quad (17)$$

The number of slots needed will be:

$$N_{slots} = \left\lceil \frac{Data_{size}}{Size_y} \right\rceil, \quad (18)$$

$$N_{slots} = \left\lceil \frac{Data_{size}}{20 \cdot 2^{\frac{\log \frac{256}{SF}}{\log 2}} - 8} \right\rceil. \quad (19)$$

The time required to transmit these slots will be equal to the number of slots multiplied by 10/15 ms:

$$Time = \frac{10}{15} \cdot \left\lceil \frac{Data_{size}}{20 \cdot 2^{\frac{\log \frac{256}{SF}}{\log 2}} - 8} \right\rceil. \quad (20)$$

Then, the number of frames will be:

$$N_{frame2} = \left\lceil \frac{N_{slots}}{15} \right\rceil. \quad (21)$$

Similarly, because the 3GPP standard uses the spare extensions as pads, the number of frames needed for the 3GPP standard is:

$$N_{frame} = \left\lceil \frac{32 \cdot \left\lceil \frac{8 \cdot (33 + TB)}{\sum_1^m (20 \cdot 2^{\frac{\log \frac{256}{SF}}{\log 2}} - 8) - 32} \right\rceil + 8 \cdot (33 + TB)}{15 \cdot (20 \cdot 2^{\frac{\log \frac{256}{SF}}{\log 2}} - 8)} \right\rceil. \quad (22)$$

6. System Validation

Here, results of the analytical calculation are compared with the simulation. The results show SF most frequently used

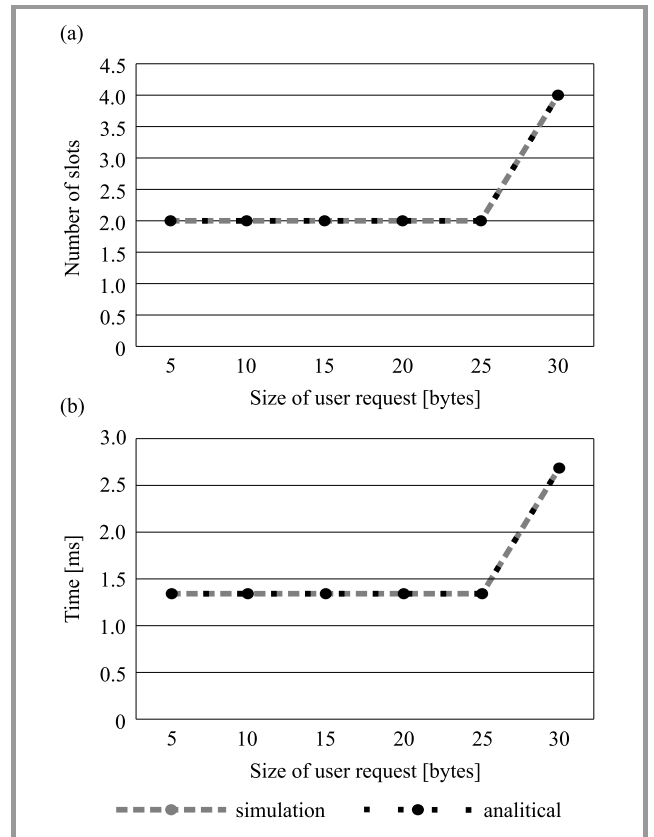


Fig. 7. Comparison of results with $SF = 32$ for: (a) slot needed, (b) time needed to transmit the info.

in the channel, which equal 32 or 64. Figure 7 shows the comparison with $SF = 32$.

Figure 7a shows the number of slots needed in S-CCPCH to send data to the user, while Fig. 7b shows the time that these slots need in order to be sent to the user. The results indicate a slight difference between the calculation results and the results obtained from the simulation. This difference could be bigger when using a SF larger than 32, as can be seen in Fig. 8, where $SF = 64$.

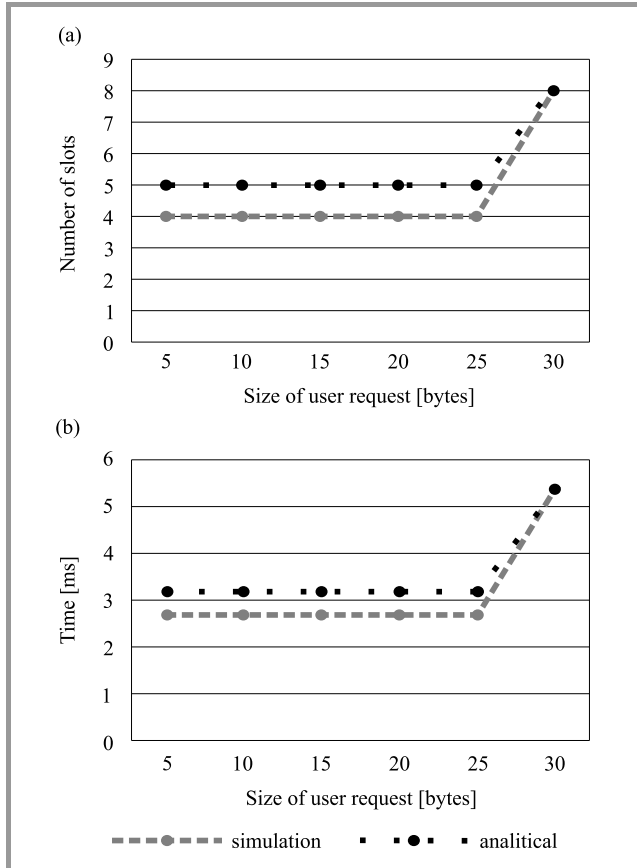


Fig. 8. Theoretical vs simulation results with $SF = 64$ for: (a) slots needed for the transmission and (b) time needed to transmit the alert.

7. System Evaluation

This section shows the results of implementing the proposed method under a simulation scenario and compares them with the 3GPP standard. The results shown are for $SF = 32$ and 64. Figure 9 presents the results of the two methods (proposed vs. 3GPP) with $SF = 32$, indicating the differences in the number of slots needed to send the information, and in the time needed to send those slots over S-CCPCH.

The performance of the proposed method is better than that of 3GPP in terms of speed at which an alert of the same size is sent. The proposed method needs less data and uses fewer slots. The reason is that the spare extensions in FACH are filled by zeros by the sender, and, TB

fields will be used to send the message, meaning that the transmission will consist of the disaster-related information plus the size of the spare extension, while in the proposed method the spare extension will be used to send the information, and the TB field will not carry any data. This will reduce the amount of data sent. Figure 10 shows the result for $SF = 64$.

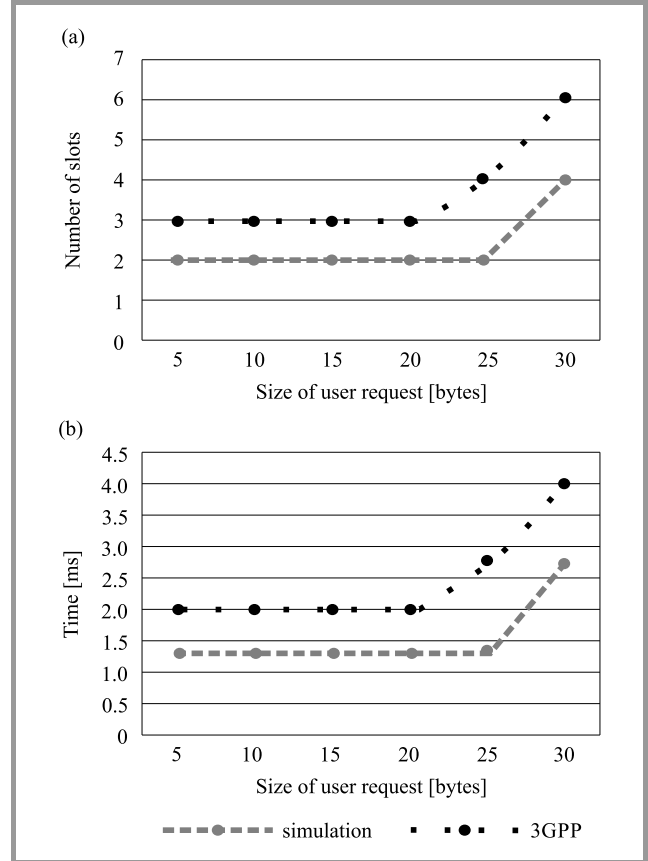


Fig. 9. 3GPP vs proposed results with $SF = 32$ for: (a) slots needed for the transmission and (b) time needed to transmit the info.

While this paper focused on transmitting the message using a 3G (UMTS) network, the idea of the proposed method can also be applied with modifications in LTE and LTE-A networks. Fortunately, LTE service providers may use the circuit switched network of UMTS and GSM when needed by the circuit switch fallback (CSFB) [44]. Hence, the proposed system may be applied in LTE and LTE-A to send warning messages. However, not all operators have the privilege of using CSFB. In this case, the proposed design may also be applied, but with different frame structures and control channels.

As mentioned earlier, UMTS uses RACH/FACH to establish a radio resource control (RRC) connection [34]. However, the channels that are used in LTE for this process, as part of RRC, are not the same as in UMTS. LTE uses PRACH and RACH with frame formats that differ from that used in UMTS. Different physical channels are used

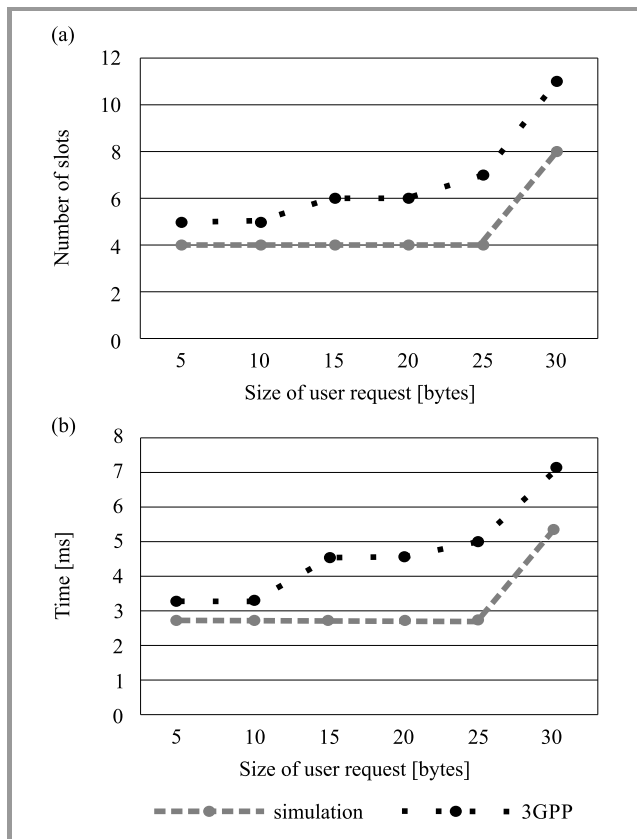


Fig. 10. 3GPP vs proposed method with $SF = 64$ for: (a) slots needed to transmit and (b) time needed to transmit the info.

as well. So, the proposed design may be applied in LTE, but with modifications in frame structure and channels used [45].

8. Conclusion

This paper proposed a new method for sending alert messages from the service provider to mobile users without the need of using the Internet or packed channels. The spare FACH extensions are used to carry the messages in UMTS. FACH is being carried using S-CCPCH.

The main contribution of this paper lies in the utilization of the spare extensions of FACH for transmitting information to the user. The spare extensions are not used in the standards as padding or guards, as they are related to FACH, not S-CCPCH.

In the 3GPP standards, FACH is mainly a part of the RRC used to establish the connection, with subsequent commencement of the process of transmitting information between the user and the mobile network. However, in many cases, FACH could carry a small amount of data using TB fields, and the transmission is the fastest in this case. So, all results shown in this paper have been compared with this scenario. Results of the evaluation show that the proposed method is capable of transmitting warning messages to users. Moreover, this transmission is faster than that in 3GPP.


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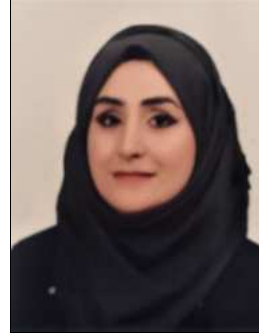
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