Applicability of Macro Sensor Network in Disaster Scenarios

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Abstract—**The efficient use of communication technologies during disaster scenarios is vital for the relief and rescue works as well as for the disaster affected people. During the disaster scenarios, links between the Radio Access Network (RAN) and the Core Network (CN) might be broken. If the link between such affected nodes can be re-established via node-to-node communication, the data from the users can be transported to the network. Thus, this utilization of node-to-node communication can be a key technological achievement for cellular networks during such scenarios. The aim of this paper is to present the possible realization of a macro site node-to-node sensor network functionality for cellular networks during disaster scenarios. The merits of 3GPP LTE technology have been utilized in this paper to present a framework for this node-to-node communication in 3GPP LTE technology.**

Keywords—disaster scenarios, LTE, node-to-node communication, WSN.

I. INTRODUCTION

Communication has played a vital role during different disaster scenarios from its early development to the present day. Communication techniques have been used for providing early information about the disaster and during the emergency rescue and relief operation for disaster affected people. Thus, during crisis events, communication is critical for disaster management. The use of wireless communication for the disaster management backs to events surrounding the sinking of "Titanic" in the night of April 13–14, 1912. The radio communication system was vital communicating with nearby ships because of which they changed their course for rescue of the passengers onboard in the "Titanic" [1]. Moreover, the Tsunami of 2004 at Indian Ocean was an alert for the world on the need for efficient communication system during an emergency for disaster management. Public Land Mobile Network (PLMN) can be an effective communication technology in the disaster scenarios to transfer the data from the sensors, establish communication between relief teams or with the victims. The Tampere Convention, organized by joint effort of UN and ITU in 1998 in Tampere, Finland, facilitates the use of telecommunication for humanitarian aid, removing regulatory barriers and in the use of frequencies [2].

When disaster strikes, various communication links might be interrupted and the communication network becomes nonfunctional. Various research works have been done to provide a prompt communication service to the relief works and people in disaster affected areas. Reference [3] presents the Wireless Sensor Network (WSN) for the disaster management and [4] shows the use of Ad hoc Networks for the rescue operation and disaster survivor detection. High Altitude Platform (HAP) system has been proposed in [5] for replacing UMTS coverage in disaster scenarios. However, HAP faces the challenge of stationary allotment of its stations due to wind and the supply of the energy. HAP system is expensive as well. The combination of cellular mobile network and the ad hoc networks leading to the Multi-hop Cellular Network (MCN) is proposed in [6] which combine the benefits of fixed infrastructure of cellular mobile networks and the flexibility of ad hoc networks. However, MCN does not scale well and it is difficult to provide uninterrupted high bandwidth connectivity to a large number of users with these networks [6].

In this paper, it has been focused on a disaster scenario, where the link between the RAN and CN is broken and thus transmission between network elements is affected. For LTE network this is the link between eNodeB and the Evolved Packet Core (EPC). The possible solution proposed in this paper is the realization of surrounded eNodeBs sites as WSN nodes to establish the relay network for transmission purpose between the affected nodes. The nodes should sense the disaster scenario and switch to sensor mode. The communication between these nodes is at the macro level and thus is termed as macro sensor network. This functionality can be realized as a "Safety Mode" and the communication blackout can be eliminated and transmission network can be re-established. The established link can provide limited services such as SMS, speech or limited data services. Thus, by utilizing the pre-existing infrastructure of 3GPP technology, an effective communication can be achieved during disaster scenarios.

II. THEORY

For the efficient node-to-node communication, the occurrence of interference from other sources should be analyzed. This section introduces the theory behind the node-to-node communication. It is assumed that the eNodeB antennas are organized into three sector sites and the network layout is clover-leaf.

A. Frequency Reuse Pattern

Reference [7] shows the frequency reuse scheme where the available frequency band is divided into several sub-bands. A set of frequencies are allocated for cell edge users in a cell with full downlink transmission power. Users in the inner cell are served with reduced power. The frequency reuse pattern for the node-to-node communication is realized such that the reused pattern proposed for the cell edge users in [7] is used for the communication between the antennas as shown in Fig. 1.

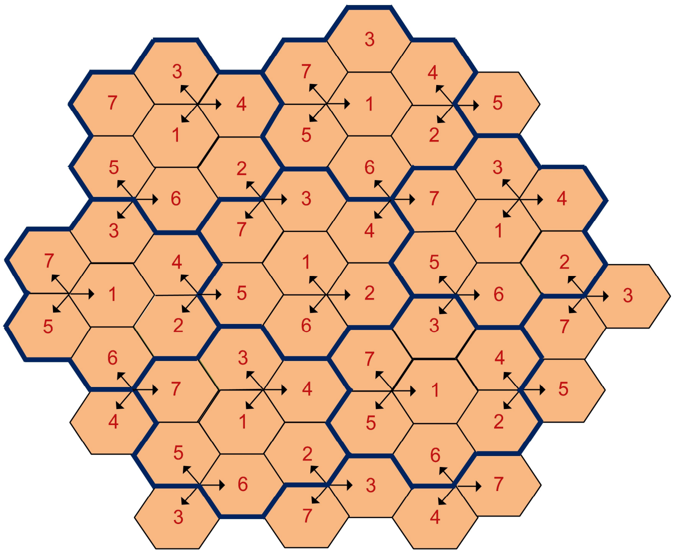

Fig. 1. Frequency Reuse Pattern.

The reuse pattern in Fig. 1 can now be used for the node-to-node communication during the disaster scenarios. The thick color boundary line shows the size of a single cluster. The reused cells are organized such that the interference from the cells with same frequency is minimized.

B. Inter-cell Interference

The effective use of resources in a cellular system can highly enhance the capacity of the system. In a cellular network employing frequency reuse across different cells, inter-cell interference occurs when neighboring cells use the same frequency band for communication. Reference [8] and [9] show a general approach of frequency reuse for inter-cell interference reduction. As shown in Fig. 2, transmitter T1 transmits a signal to its desired receiver R1. At the same time transmitter T2 also transmits a signal. Then, R1 receive a signal from T1 as well as from T2. At the receiver R1, the signals from T1 and T2 are superimposed and the signal from T2 is interference for R1. Moreover, higher interference leads to low Signal to Interference and Noise Ratio (SINR) value which finally implies low quality of the wanted signal.

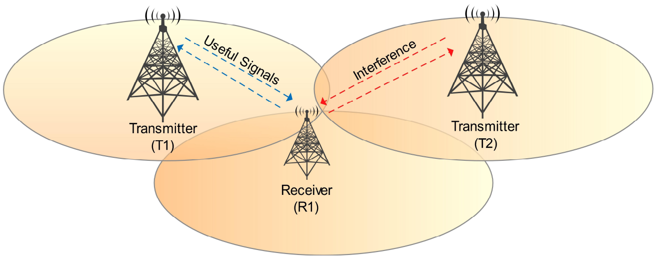

Fig. 2. Radio Communication System.

In order to calculate the inter-cell interference, the following equations are needed. First, the SINR is defined as

$$SINR = \frac{P_{\mathrm{r}}}{P_{\mathrm{inter-cell}} + P_{\mathrm{intra-cell}} + P_{\mathrm{n}}}, \tag{1}$$

where P_{r} is the received power, $P_{\text{inter-cell}}$ is the other-cell interference power, $P_{\text{intra-cell}}$ is the inner-cell interference power and P_{n} is the noise power.

The signal power S of the desired transmitted signal received by the receiver can be calculated as

$$S = P_{\mathrm{td}} + G_{\mathrm{td}} + G_{\mathrm{r}} - PL, \tag{2}$$

where P_{td} is the transmitted power, G_{td} is the antenna gain of the transmitted station, G_{r} is the antenna gain of the desired receiver station and PL is the path loss. The interference power of the neighbor co-channels received at the same receiver can be calculated as

$$I = P_{\mathrm{ti}} + G_{\mathrm{ti}} + G_{\mathrm{rd}} - PL. \tag{3}$$

Here P_{ti} is the transmit power from interfering station, G_{ti} is the antenna gain of interfering transmit station, G_{rd} is the antenna gain of the desired receiver station measured at the angle of arrival of the interfering station.

C. Path loss

The proposed node-to-node communication is at the macro site layer, i.e. the base station antennas are at towers, and thus the assumption is that the antennas have Line-of-Sight (LOS) visibility between each other and the Fresnel zone is free. Hence, free space path loss model can be utilized to predict the signal strength at the receiver. The equation can be expressed as

$$PL(\mathrm{dB}) = 32.45 + 20 \cdot \log_{10}(D) + 20 \cdot \log_{10}(f), \tag{4}$$

where D is the distance in km and f is the frequency in MHz. Free space path loss model predicts that the received power declines as a function of the distance between the transmitter and the receiver.

D. Wireless sensor network

The role of WSN can be vital for the disaster management during the disaster scenarios. WSN can be used for object tracking, monitoring and transmitting environmental information and for object detection as well. The sensor node sends its data to the sink or the fusion center, which is responsible for processing and extracting the sensor data. This delivery of data from the node to the sink may follow multiple-hops. In this paper, the functionality of sensing and the multi-hop routing approach of WSN are used to deliver the data to the desired destination, which can be from an eNodeB to the EPC, or vice versa. Moreover, the sensor network which is ad hoc in nature has the capability of minimum dependence on network planning and the capability of nodes to self-organize and self-configure without the involvement of the central controller. Hence, an operational ad hoc network should cope with the dynamic restructuring of the link. Thus, in ad hoc network, two different nodes can communicate with each other via other intermediate nodes.

The topology management is a key issue in WSN. Reference [10] states the topology management procedure including the topology discovery algorithms. In this paper, the WSN that is formed during disaster scenarios consists of a various number of sensor nodes communicating over the wireless links using a fixed network infrastructure. Thus, the routing protocol for WSN has to ensure a reliable multi-hop communication. References [11–13] describe various routing protocols which can be used in WSN, but this study is not limited to a specific routing protocol.

III. EXAMPLE SCENARIOS

The example scenarios are based on the frequency reuse scheme designed for the node-to-node communication during disaster scenarios in rural areas but are not limited to them. The results were calculated for the 800 MHz bandwidth.

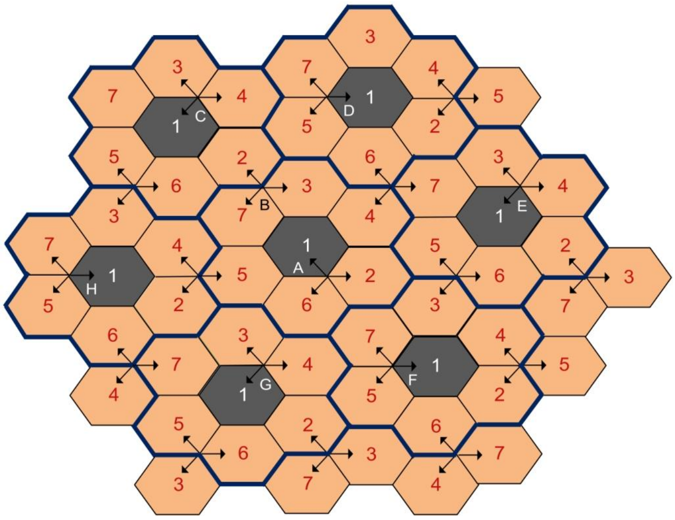

Fig. 3. Frequency reuse pattern with 1. tier of interfering nodes.

Fig. 3 shows the frequency reuse pattern with the first tier of interfering nodes. This study considers only the first tier of interfering nodes, since they are causing the majority of the interference. The cells with the frequency reuse of frequency number 1 are shown by dark grey color. Node A is the transmitting node, B is the receiving node and nodes C, D, E, F, G and H are the interfering nodes. The effective gain of the transmitting, receiving and the interfering antennas are included in the calculation. The angle of reception of the signal at the receiver antenna varies according to the location and the transmission from the interfering nodes. The inter-site distance (ISD) between neighbor eNodeBs is assumed to be equal. The carrier power and the interference power is calculated from the transmit power, the gain of the antennas and the path loss between them. Then, the SINR value is calculated.

The capacity of the resulting node-to-node link is determined from the calculated SINR values. The bandwidth scalability of the LTE network is utilized for the frequency reuse planning and for the capacity analysis.

IV. RESULTS

LTE technology with OFDMA radio access scheme is selected for the downlink transmission. This study considers OFDMA for both uplink and downlink in node-to-node transmissions. OFDMA yields to a frequency structure which divides the data over a number of sub-carriers. The spacing between two sub-carriers is fixed at 15 kHz. One Resource Block (RB) has 12 sub-carriers in frequency and 14 continuous symbols in time. Thus, one RB is 180 kHz in frequency and 1ms in time. The bandwidth scalability property of LTE allows 1.25, 2.5, 5, 10, 15, 20 MHz frequency band to provide the service. Fig. 1 shows the reuse pattern with 7 different frequencies in a transmission cluster. In this paper, it is assumed that each frequency band assigned is 2.5 MHz from the total of 20 MHz LTE band. Thus, 17.5 MHz is assigned for the node-to-node communication and remaining 2.5 is assigned for the users. These frequencies can be utilized both in the uplink and downlink directions. User band of 2.5 MHz is reused in every cell based on 1/1 reuse concept assuming high quality scheduler in LTE technology. Correspondingly, if 1.25 MHz is used, 8.75 MHz could be reserved for transmission and 11.25 MHz for the users.

The SINR was calculated with (1)–(4) and the resulting SINR equals to 5.92 dB. Table I shows that the calculated SINR values are the same because the ratio between the carrier power and the interference power is approximately the same for different inter-site distances. Comparing these result values with the recommended value of SINR presented in [14], it can be noted that the implementation of QPSK modulation technique with 3/4 or 4/5 coding rate is possible.

TABLE I
SINR VALUES FOR DIFFERENT ISD.

Inter-site Distance (m)	2000	3000	6000
SINR (dB)	5.920	5.919	5.917

3GPP specification TS 36.213 specifies the MCS and TBS for LTE. Reference [15] gives the mapping between MCS Index, Modulation Order and the TBS Index. The antenna of LTE assigns the MCS Index and the RB on the basis of CQI for the downlink transmission. This CQI value depends upon the SINR. Reference [15] also specifies the mapping between TBS index, the number of RB and the corresponding TBS value. From this mapping, the possible peak data rate that QPSK can provide, based on the calculated SNIR value, was determined to be 1864 kbps. Moreover, the peak rate of 3728 kbps can be achieved for 2x2 MIMO, and 7456 kbps for 4x4 MIMO systems.

V. OPERATIONAL FRAMEWORK

The framework has been developed for the various events associated with the node-to-node communication during the disaster scenarios. These events include the detection of the disaster scenarios by the nodes, the events related to the establishment of the path between the nodes and the events that should be triggered from the CN.

A. Disaster Detection and Link Establishment

In this paper, the disaster scenario corresponds to a situation where the link between the eNodeB and the CN is broken. This corresponds to situations, where the link is physically broken, but it can also be considered in situations where the logical connection is temporarily unavailable.

Fig. 4 shows the flow chart for the detection of the disaster scenario. When the link between the eNodeB and the EPC is broken, eNodeB should detect this event and then it should switch its functionality to macro sensor mode. In macro sensor mode, eNodeB should work with LTE functionality as well as with sensor node functionality. With this functionality, node should detect the disaster events, should perform route establishment with neighbor node and should act as relay hop.

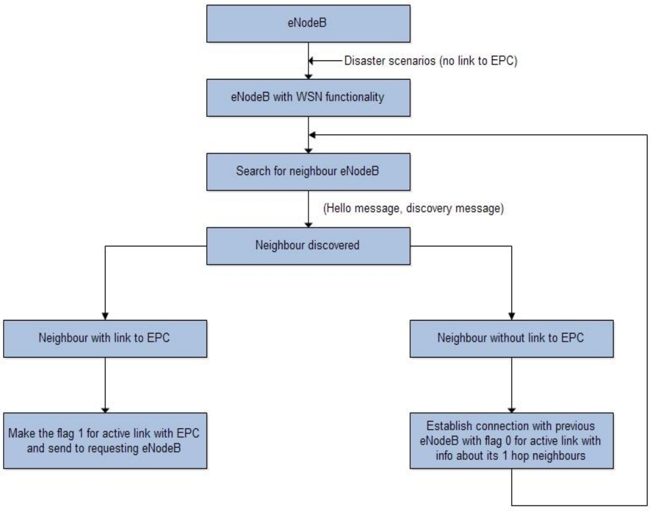

Fig. 4. Node-to-node communication flow chart.

The link establishment procedure uses an efficient protocol to establish the link with the most preferred neighbor node. A node sends the discovery message (hello message) to the neighbor nodes. The receiver can reply with the positive or negative response. If the response is positive, then in the reply message, the QOS information is also sent to the transmitting node. The receiver node can be the node with the active link or with the inactive link with the EPC. If the receiving node has active link to EPC, then this is the final hop. Otherwise, this node searches for another neighbor node with active link to EPC. All the route information can be stored in the cache in each node.

B. Events from CN

The sensor mode functionality is activated at the nodes which are affected by the disaster. But to transport the data from such nodes to the CN, certain number of eNodeBs with the active link to the CN should also be initialized with the sensor network functionality.

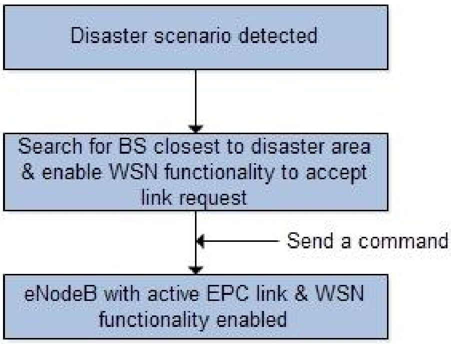

Fig. 5. EPC events.

Fig. 5 shows the operation and maintenance entity of EPC that should detect this fault situation and should locate the nodes in the geographical areas. Then, EPC should send a command to the unaffected nodes in the vicinity of the disaster area to enable the sensor mode functionality. These nodes at the vicinity will act as nodes between the EPC and the affected nodes to facilitate the delivery of the data to and from the network.

C. Network Restoration

The maintenance of the network can re-establish a communication link between the affected eNodeBs with the EPC. Then, the repaired node should act as a last hop for providing the relay function to the EPC. Once, role of the repaired node in the node-to-node communication is over, it can notify EPC and should switch back to the normal state.

VI. CONCLUSIONS AND FUTURE WORK

This paper presented the new functionality of node-to-node communication to facilitate the communication during the disaster scenarios. To enable the node-to-node communication during the link outage of RAN and CN, the realization of LTE radio network as a macro sensor network is proposed to maintain the communication.

The results presented in this paper show that a node-to-node communication can be established in LTE during the disaster scenarios. Furthermore, this type of backup node-to-node communication would be strongly limited in UMTS due to the frequency constrains. Correspondingly, node-to-node approach could be implemented in GSM with reduced capacity also due to frequency constrains.

The device-to-device communication is considered as the key technology for the future evolution of the LTE technology. The study of proximity-detection functionality for device-to-device communication is shown in [16–17]. Further, the LTE-Advanced has introduced the concept of Relay Nodes for the efficient heterogeneous network planning. The Relay Node is connected to the Donor eNodeB via radio interface [18]. The future work should take these approaches into account.

The node-to-node communication for the cellular network has opened a new research area in the field of communication. The SON technology is also required to implement the sensor mode functionality, and thus even extends this new research area. The complexity and bottle neck from the volume of data generated by the users to the node-to-node communication should also be studied. The use of maximum ratio combining or the switched combining can be a good research area to study the signal reception through two different antenna links.

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