A Network and Position Proposal Scheme using a Link-16 based C3I System

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ABSTRACT
The smart usage of hi-end military technological solutions in daily activities makes people life better. This paper describes a network and position proposal scheme in respect of technical networking and positioning information. A Link-16 based Command, Control, Communication and Intelligence (C3I) system is established among the mobile devices. Each device knows its geographical position using its GPS. A network along with a possible good position for user's service is proposed, fulfilling his/her requirements for comfortable work.
Key words: Network selection, position proposal, Link-16, C3I systems, WiFi, WiMAX, GPRS, UMTS, LTE

INTRODUCTION

Nowadays, the wide spread of wireless networks has challenged the research community into the development of sophisticated network selection schemes. In addition, military research and development departments have produced state of the art technologies which can offer usable solutions for making people life better. The proposed scheme combines technical networking information with position related users' opinions to accomplish network proposal along with position proposal. A Link-16 based C3I system is established among the mobile devices. Each device knows its geographical position using its GPS. Technical information about the WiFi, WiMAX, GPRS, UMTS and LTE networks which are inside the range of each device as well as positioning information is exchanged. Thus, each device is informed about the positions of the other devices and the available networks in their ranges. Users also share their position related opinions. The system relies on the entire exchanged information and accomplishes the network as well as the position proposal. It is also notable that each device can connect to a network either directly or via another device in mesh mode.

The remainder of the paper is organized as follows. Firstly, related research literature as well as an overview of the standards followed in this study is described. Then, the software architecture that supports the prototype application, the software elements and modules are presented. The final section concludes our work and presents possible future extensions.

MATERIALS AND METHODS

Related Work

The rapid increase of wireless network technologies has lead into the development of sophisticated network selection schemes. This section makes an overview of some network selection approaches proposed by the scientific literature.

The work presented in [1] describes a user-centric network selection scheme. It is based on user preferences as well as on cross-layer information including application, link and physical layers. Furthermore, it is applied in a heterogeneous network environment and also takes into account vertical handover situations. The network selection along with the handover decisions are made by the user equipment. In addition, the proposed network selection and handover optimization intends on the reduction of handovers' frequency. The authors propose three algorithms for handovers' frequency reduction. According to their experimental results, these algorithms achieve a successful balance of the user requirements with the handovers' frequency.

The authors of [2] describe a network selection scheme for IEEE 802.11 networks. The available networks are evaluated according to the PSQA method. Objective Quality of Service (QoS) parameters such as bandwidth, jitter and packet loss are combined with subjective Quality of Experience (QoE) parameters such as "the video quality is good". The QoE parameters are estimated in respect of the Mean Opinion Score (MOS) technique. Especially, a Random Neural Network (RNN) is used for statistical learning of the MOS scores and provides automated QoE evaluation for each network. According to the authors, the prerequisites to enable the application of the PSQA methodology are the following:

- Step 1 - Quality-affective factors and Distorted Video Database: QoS factors are selected and a range of values for each factor is defined. A set of factors along with specific values is called “configuration”. Then, a video database which contains many configurations is created.
- Step 2 - Subjective Quality Assessment: Subjective evaluation of the configurations which are contained in the video database is carried out, according to the MOS methodology. Two similar databases which contain the configurations and the relative MOS scores are created. The first one is referred as “training database” and the second as “validation database”.
- Step 3 - Learning of the quality behavior with RNN: The result of the step 2 is a qualitative evaluation of the video database’s contents that created in stage 1. The RNN receives as input the training database and attempts to train itself according to its data. A function f() verifies if the "knowledge" which is acquired by the RNN converge in respect of the validation database. If the RNN’s knowledge is relatively close to the validation database, the RNN is positively evaluated. Otherwise, a review of diverge data is performed, until the RNN be well trained.

When a user needs to make a network selection, each access point informs him/her about its estimated QoE. This information comes from previous connected users to the access point and is included in either beacon or probe response frames. The user defines his/her minimum requirements for QoE in respect of the MOS scale. User’s terminal takes into account only the networks that meet the minimum QoE requirements and performs the network selection.

The authors of [3] propose a network selection scheme that uses mobility related factors. It is applied in heterogeneous networking environments which include UMTS, WiMAX, WiFi and Bluetooth networks. The networks are classified into two groups. The first one is referred as “ubiquitous networks” and includes UMTS and WiMAX networks. The second group includes WiFi as well as Bluetooth networks and is referred as “hot spot networks”. The authors assume that the deployment of hotspot networks is independent of the ubiquitous networks and can be modeled using the Poisson point process [4]. The algorithms SAW [5], MEW [6], TOPSIS [7] and GRA [8] are used for network ranking. Several experiments are presented and the importance of mobility related factors is demonstrated.

[9] describes a network selection scheme which is applied in a heterogeneous network environment, consisted of WiFi, WiMAX, UMTS and LTE networks. The entire mechanism leads on the selection of the best network, according to the current networking conditions as well as to potential future network states. Furthermore, the proposed scheme is evaluated in comparison with two other network selection strategies, the predefined and the opportunistic. The predefined strategy selects the network that provides the higher signal strength. A key disadvantage of this strategy is that the higher signal strength does not always imply on a high QoS level. On the other hand, the opportunistic strategy selects the network that provides the best QoS. It leads on a large number of handovers, in respect of the rapidly and dynamically changed networking environment. The goal of the proposed scheme is the balance of the provided QoS with the total number of handovers, which leads on a more efficient usage of the entire network resources.

Materials

This section presents an overview of the technologies that are used by the proposed scheme. These technologies include the GPS [10], Link-16 tactical data link [11], C3I systems [12], Ad-hoc [13] and Mesh networking architectures [14] as well as WiFi [15], WiMAX [16], GPRS [17], UMTS [18] and LTE [19] networks.

GPS

The Global Positioning System (GPS) relies on a grid of satellites to make available positioning services. Precise positioning information about the terminals, such as geographical longitude, latitude, altitude, speed and direction of motion, is provided. In conjunction with mapping software this information can be graphically illustrated. The positioning system forms a global network, which covering land, sea and air. The entire GPS infrastructure is consisted of:

- Space segment: It consists of a satellite network, in which all satellites are flying at a height of 12552 miles or 20200 kilometers above the sea level.
- Ground control segment: It includes ground centers, which offer manipulation and support

functionalities.

- End user segment: It is also referred as user equipment or GPS terminal. It can be used during a simple walking, in vehicles or maritime vessels and usually has small dimensions.

Link-16

The Link-16 is a state of the art technology that fulfills the limitations of all previous NATO's tactical data links. It is also referred as Tactical Data Information Link-J (TADIL-J) and operates in the range of the UHF Lx Band (960-1215 MHz). Bi-directional tactical, voice and navigation data communication among the Participating Units (PUs) is provided. Frequency modulation, frequency hopping and time-sharing methodologies are also applied. The defined architecture does not contain fixed nodes and thus there is no single point of failure.

The major infrastructure is consisted of two main terminal types, the Joint Tactical Information Distribution Systems (JTIDS) and the Multifunction Information Distribution Systems (MIDS). In each JTID, predefined time slots for data transmission and reception, are assigned. Slots' lengths are equal to 1/128 seconds or 7.81 milliseconds. Additionally, each slot is divided into 51 frequencies, which are inside the range of the UHF Lx Band. It is a 3MHz gap between adjacent frequencies. Special filters exclude sub-spectra of 1008-1053MHz and 1065-1113MHz, which are used by the IFF [20] and TACAN [21] systems, respectively. Parallel communication on multiple sub-networks is made available, simply by giving a different frequency hopping method to each sub-network. Thus, sub-networks with specific missiles can be created. A PU participates only on one sub-network during a time slot. Also, different frequencies are used for downlink and uplink. These frequencies are changed every 13 milliseconds according to a predefined pseudo-random frequency hopping algorithm. There are 128 possible sub-networks available for use, but due to the limitation of the 51 frequencies, almost 30 sub-networks can operate in parallel without interferences. If there are parallel transmissions in the same frequency, a terminal takes into account only the closest transmission to it, in respect of the received signal strength.

The Link-16 provides increased data transmission rates compared with the older tactical data links. It also supports a variety of messages that did not exist in earlier links. Furthermore, in addition to the regular tactical data, extra functionalities are provided, such as air-navigation data transmission. Therefore, the real increase of the exchanged data volume exceeds the 300% compared with older links.

The messages of Link-16 consisted of two parts, the header and the data. The header provides meta-information about the message, such as the message type and the source PU. The data part contains the tactical information. The following message types are defined:

- Fixed format messages: These messages are also referred as "J series messages" and used for tactical data exchange. Fields for accurate and correct data transfer are included. Innovative functionalities that improve the effectiveness of tactical data exchange compared with the earlier data links are provided, such as:
  - Number of Participants: In each PU a unique address is assigned. It is a five digit octal number inside the range of 00001-77777, which enables a maximum support for 32,767 different PUs. To better understand the importance of this upgrade in compare with earlier links, the Link-11 [22] accepts three digit octal addresses inside the range of 001-177, which enables a maximum support for only 127 PUs.
  - Number of Targets: A five digit octal number inside the range 00001-77777 or AA000-ZZ777 is assigned to each target. It enables a maximum support for 524,284 different targets and results in an extremely increase in compare with the 4.092 possible targets that are supported from earlier links.
  - Target quality: The quality of the targets is related to the accuracy of each target's position reporting. Its values are inside the range of 0-15 providing accuracy better than 20 meters. To understand the importance of this upgrade in compare with earlier links, the Link-11 defines values from 0 to 7 and its accuracy is worse than 3 nautical miles.
  - Target identity: Each target's identity includes features such as target's activity, platform type and ethnicity.
  - Status Filial PUs: It provides detailed status information of the filial PUs that includes equipment state, communication channels with radars and missiles, fuel levels and weapons' capabilities. This type of information does not provided by earlier links.

  - Data Accuracy: Increased data accuracy for position, velocity, height and direction is provided. It enhances the efficient matching of targets which are referred by multiple PUs.
  - Lines and Regions: Information about multi-segment lines and areas of each size and shape can be transmitted. PUs can also exchange information about flight corridors, weapons range etc.
  - Geodetic Position Reporting System: Each PU's and target's position is referred in respect of a geodetic system which includes geographical longitude, latitude and altitude. It allows the reference of PUs and targets anywhere in the world and provides useful information on GPS systems and weapons. The earlier links used the Cartesian system which is based on the position of a reference unit, limiting thus the geographical range of the entire system.
  - Electronic warfare: Increased capabilities for electronic warfare parameters transmission are provided.
  - Ground points and targets: In addition to air and sea targets that can be identified by earlier links, ground points and targets such as building and vehicles, can also be specified.
  - Educational targets: The system provides the ability of creating virtual targets either in actual military exercises or under simulations for educational purposes.
- Variable format messages: These messages do not follow a specific structure and are used for the exchange of user defined data, which are different from the regular tactical data. Simultaneously with the fixed format messages, fields for accurate and correct data transfer are included.
- Free text messages: Text messages do not have a specific structure and do not contain fields for accurate and correct data transfer. They are usually used for digitized voice transportation.
- Round Trip Timing messages: This type of messages is used for terminals' synchronization. The message contents as well as the transmission wave form are encrypted, increasing the entire system's security. Especially, the messages are encrypted in respect of a variable. On the other hand, the transmission waveform is encrypted by another variable which defines the following:
- The frequency hopping method, so that security achieved against the interference and eaves dropping.
- A pseudo-noise which is merged with the main signal and make it to seem like a common noise.
- A variable size jitter at the beginning of each transmission is also introduced, achieving greater resistance to interference.

Every JTID terminal can participate in one or more Network Participation Groups (NPGs). Each NPG defines a specific function and manages messages that correspond only to its role. As result, separate NPGs for electronic warfare, secure speech and air traffic control can be available, improving the entire system's effectiveness. The Link-16 JTIDS/MIDS telecommunication infrastructure also provides a wide variety of important features. These features are implemented into the JTIDS/MIDS terminals and maintain the network operational, without needing any information from the transmitted tactical data. They also provide accurate position, status, navigation and identification information about each PU. Especially, the following features are provided:

- Accurate position and identification of participants: Each terminal automatically sends Precise Participant Location & Identification (PPLI) messages. They indicate PU's position and provide detailed information about its status. The PPLI messages are necessary for the PUs' synchronization. Each PU that receives a PPLI message can itself calculate and correct its timing.
- Relative Navigation: It helps the definition of the exact distances among the PUs, which is achieved by measuring the arrival times of the received PPLI messages in each PU. It is also useful for the PUs' synchronization. If two or more PUs have independent accurate knowledge of their position (e.g. using GPS), then combining the relative navigation with the PPLI messages all the participant units will have an accurate position determination.
- Synchronization: The correct timing enables a unit to participate in the network and exchange messages with other PUs. When a unit connects to an existing network, it receives a "start message" from a predefined network time reference unit. Then, through Round Trip Timing messages it is synchronized with the entire network.
- Secure speech channels: The JTIDS/MIDS terminals support two parallel and secure voice

channels. These channels transfer digitized voice and enable the capability of parallel voice communications between PUs.

- Retransmission: The UHF Lx band as well as the frequency modulation that is used in the Link-16 enables communication only between units that maintain line of sight (LOS). For an aircraft the LOS can be up to 300 nautical miles, but because of the curvature of the Earth it is limited approximately to 25 nautical miles for the ground units. Also, there are a number of additional factors that limit the range of the communication signal. Such parameters are the existence of barriers such as mountains and large buildings, which create hiding effects. With retransmission each PU can act as repeater, increasing the range of the entire network. Furthermore, many alternative data flow routes can exist, improving system's durability.
- Tactical Air Navigation: Air navigation information exchange is also supported by the JTIDS/MIDS terminals.
- Embedded Test: The JTIDS/MIDS terminals include embedded tests, which enable monitoring and failure correction functionalities. It increases system's reliability and reduces the required time for fault recovery.

C3I Systems, Ad Hoc and Mesh Networks

In military terminology, the C3I acronym stands for command, control, communications and intelligence. The ability of military commanders to direct forces is referred as "command and control". The "communications and intelligence" terms refer to the required communications that enables the coordination of the PUs as well as the artificial intelligence among them, respectively. An underlying ad-hoc or mesh network, which includes the PUs, is usually used in C3I systems. PUs interact each other and tactical data such as positioning and PUs' state related information are exchanged. C3I systems can be considered as hybrid systems which combine ad hoc and mesh functionalities.

A wireless ad hoc network is a decentralized type of network, which does not rely on any existing infrastructure, such as routers or access points. Each node can participate in data routing. The determination of which nodes forward data is made dynamically according to current network's connectivity. The decentralized nature of wireless ad hoc networks makes them suitable for applications such as C3I systems. Additionally, the quick installation and minimal configuration requirements, makes wireless ad hoc networks suitable for emergency situations such as natural disasters as well as for inaccessible areas.

In mesh networks each node can also perform as an overlay router. When a routing technique is applied, each message is transferred to the destination node by hopping through all the intermediate nodes. A routing technique also enables network's reconfiguration to manipulate failures such as intermediate broken paths or nodes. Usually, mesh networks are compared with ad hoc networks. An ad hoc network does not require any network infrastructure. On the other hand, an underlying network infrastructure is required by a mesh network. Thus, mesh and ad hoc networks can be considered as different network types, but they can also be combined in hybrid solutions. A mesh network may also offer ad hoc functionalities.

WiFi and WiMAX

Wireless LAN is the most famous network type for Internet access. A wide variety of 802.11 standards, including 802.11b, a and g, is available. These standards usually share many similar features, such as the same media access protocol, the CSMA/CA, as well as the same frame structure. The ability of reducing the transmission rate for covering longer distances is also provided. Moreover, infrastructure as well as ad hoc mode is supported. The 802.11b and g operate in the frequency range of 2.4-2.485GHz. The 802.11a operates in the frequency range of 5.1-5.8GHz. On the other hand, 802.11a and g offer maximum data rate up to 54Mbps, while 802.11b offers 11Mbps. A newer WiFi protocol, the 802.11n, uses antenna multiple-input multiple-output (MIMO) technology, which increases the maximum data rate. Finally, the IEEE 802.11s and 802.11e are specialized in providing mesh as well as QoS services, respectively.

The IEEE 802.16 WiMAX family of standards is applied in wireless MANs. There are many 802.16 standards available. The 802.16e provides mobility support at speeds up to 130 kilometers per hour. A maximum data rate of up to 30Mbps is also offered. A base station oriented as well as mesh infrastructures are supported. The base station coordinates the link-layer packet transmission in both downstream and upstream. Finally, OFDMA multiplexing is applied enhancing the entire system's durability.

GPRS, UMTS and LTE

The General Packet Radio Service (GPRS) is standardized by the European Telecommunications Standards Institute (ETSI). It provides internet access over the Global System for Mobile Communications (GSM), which is the world's leading standard in digital cellular networks. Peak data rates up to 114 Kbps are provided. Two major network elements are introduced, the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN). The SGSN interacts with the mobile stations and also maintains information about their locations. Additionally, it communicates with the GGSN. Finally, the GGSN is a gateway that provides access to a data network.

The 3GPP Universal Mobile Telecommunications System (UMTS) is applied in cellular network topologies. Data rate up to 384Kbps along with mobility support is offered. In addition, transmission rates are increased up to 2Mbps for stationary users. The High Speed Downlink Packet Access (HSDPA) and the High Speed Uplink Packet Access (HSUPA) provide data rates' improvements. Especially, these technologies are essential evolution of UMTS. They provide data rates up to 14,4Mbps and 5,8Mbps for the downlink and uplink, respectively. A UMTS network consists of two main entities, the core network (CN) and the UMTS Terrestrial Radio Access Network (UTRAN). The CN is responsible for routing telephone calls as well as for data connections to external networks. The CN consists of two sub-domains, the circuit-switched (CS) and packet-switched (PS). The CS sub-domain provides access to PSTN/ISDN infrastructures, while the PS provides access to IP networks. The UTRAN is responsible for the wireless part of the network. It consists of a radio network controller (RNC) and NodeBs which provide coverage in the corresponding cells. A NodeB is connected to the user equipment (UE) as well as to the RNC.

The 3GPP Long Term Evolution (LTE) enhances the UMTS in a variety of features. LTE provides improved specifications compared with the previous cellular systems' generation. These specifications include peak data rates up to 300 Mbps for downlink and 75Mbps for uplink as well as more effective QoS. LTE integrates the Orthogonal Frequency Division Multiplex (OFDM) technology. Two access schemes are defined, one for the downlink and one for the uplink, respectively. Especially, the downlink uses Orthogonal Frequency Division Multiple Access (OFDMA). On the other hand, the uplink uses Single Carrier Frequency Division Multiple Access (SC-FDMA). MIMO is also supported and enhances the entire system's efficiency. A key element of the LTE architecture is the Evolved Universal Terrestrial Radio Access Network (EUTRAN). It contains a node which is named eNodeB (eNB) and interacts with the User Equipment (UE). The eNB also implements the physical (PHY), Medium Access Control (MAC), Radio Link Control (RLC) and Packet Data Control Protocol (PDCP) layers of the LTE architecture. Functions such as radio resource management, scheduling, QoS manipulation and admission control are also performed by the eNB.

Methods

The proposed scheme combines technical networking information with position related users' opinions, to accomplish network and position proposal. It is implemented over the Android mobile platform [23] which has been extended for supporting the Link-16 technology. Each device has two network interfaces, a Link-16 as well as a main interface. A C3I system, which is used for information exchange among the devices, is established using their Link-16 interfaces. The Link-16 provides enhanced security, stability and interference robustness to the C3I system. Especially, the Android devices are considered as the PUs of the Link-16 architecture and communicate each other using the Link-16's message types. On the other hand, the main interface is used for interaction with WiFi, WiMAX, GPRS, UMTS and LTE networks. Figure 1 presents a sample view of system's architecture.

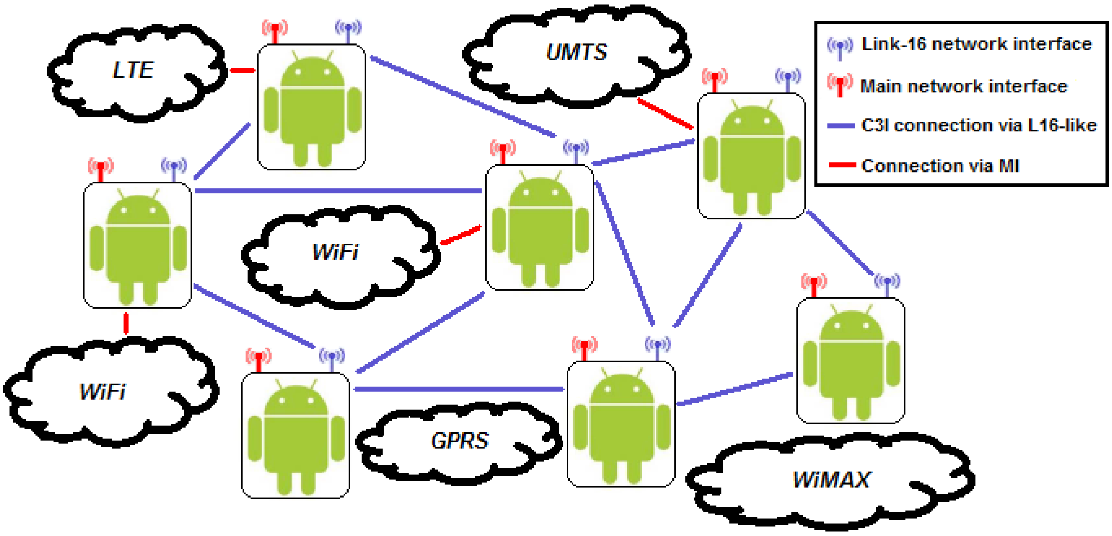

Figure 1. A sample view of system's architecture

Each device is informed about its geographical position using GPS. Then, it is connected sequentially to all the available networks which are inside its range, makes measurements and extracts networking technical information, such as throughputs, packet losses, link utilizations and signal strengths. This information along with positioning data is exchanged among the devices. Thus, each device is informed about the positions of the other devices as well as the available networks in their ranges. The entire procedure is presented in figure 2.

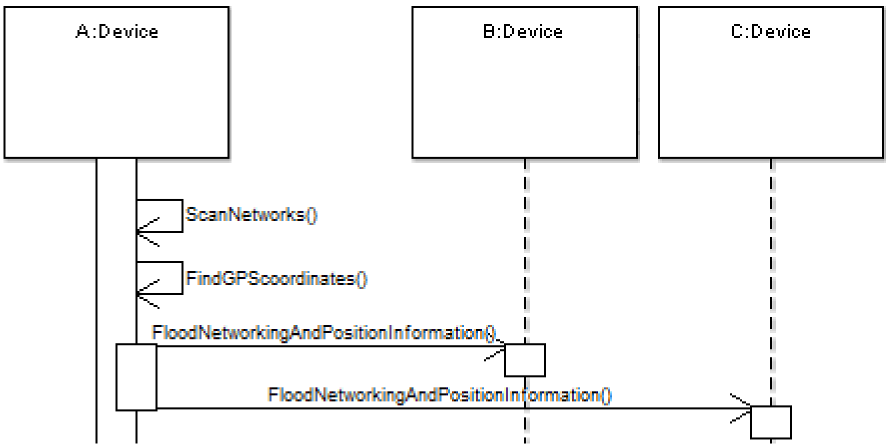

Figure 2. Networking and positioning information exchange

Users also share their position related opinions along with relative Position Mean Opinion Scores (PMOS). The definition of PMOS score is explained in terms of position suitability as shown in Table 1. Furthermore, figure 3 presents an example of this interaction among the devices.

Table 1. Position Mean Opinion Scores – PMOS

Positioning MOS	Explanation
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

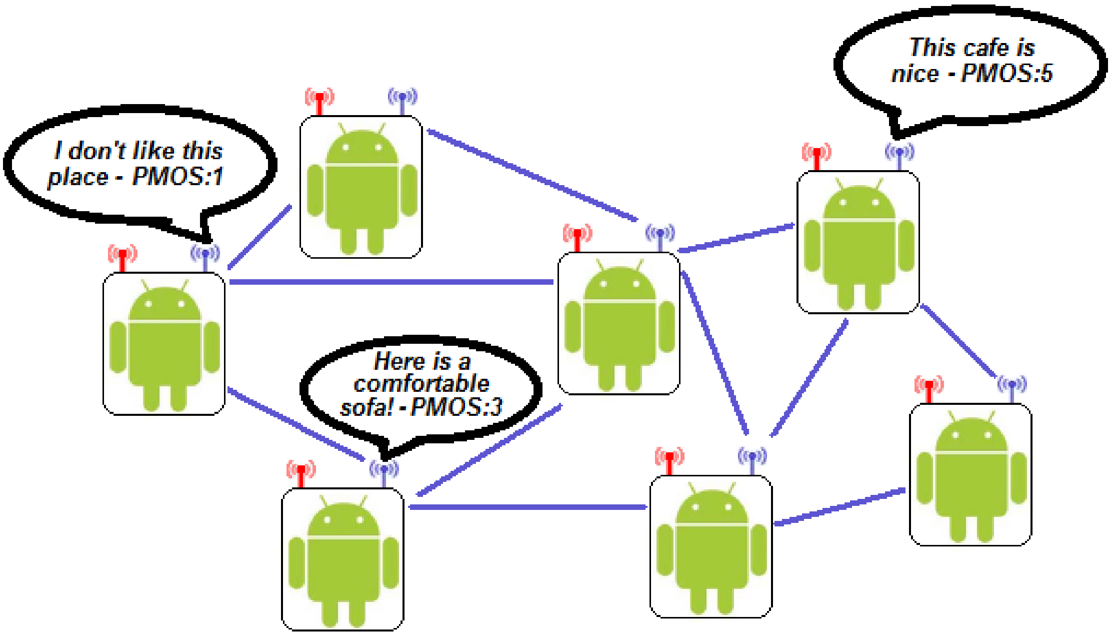

Figure 3. Users share their position-related opinions using instant messaging

Each device relies on the entire exchanged information and calculates a Network-Position Score (NPS) for each available network, according to the formula:

$$NPS = w_t \cdot (1 - \frac{1}{t}) + \frac{w_l}{l} + w_s \cdot (1 - \frac{1}{s}) + \frac{w_u}{u} + w_p \cdot PMOS$$

where t, l, s and u stand for throughput, packet loss, signal strength and link utilization, respectively. Additionally, w_t, w_l, w_s, w_u and w_p represent the weights for throughput, packet loss, signal strength, link utilization and PMOS, respectively. The system proposes the network along with the position which accomplishes the highest NPS.

A device connects to a network either directly or via another device using the mesh functionality, as presented in figure 4. In this figure the "Access Network" can be a WiFi, WiMAX, GPRS, UMTS or LTE network. Especially, as specified of the implemented mesh functionality, a device "A" which is connected to another device "B" via the Link-16 interface, accesses the internet via B's main interface.

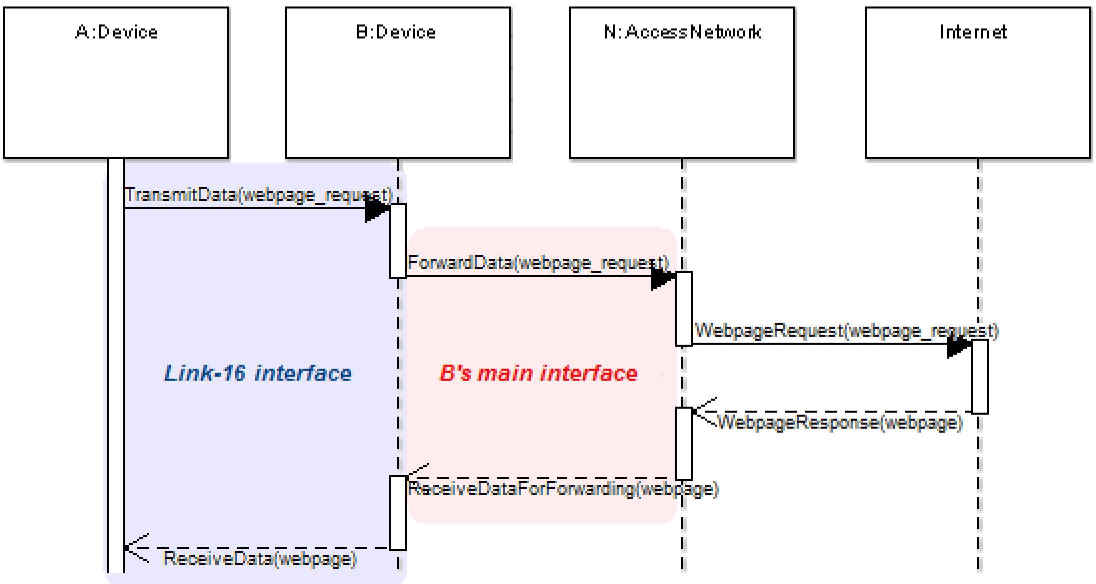

Figure 4. A device interacts with a website via another device

RESULT AND DISCUSSION

This section describes an example of our system's functionality. The entire system is emulated using the Android emulator, which has been extended to fulfill system's requirements such as the two network interfaces (Link-16 and main) per device. A Link-16 based C3I system is established among the emulated devices. WiFi, WiMAX, GPRS, UMTS and LTE networks are also emulated. Initially, each device knows its geographical position using GPS. Then, it is connected sequentially to the available networks which are inside in its range and makes measurements. The devices communicate each other and exchange positioning information along with networking technical information. Thus, each device is informed about the positions of the other devices as presented in figure 5, as well as about the networks which are inside the other devices' ranges.

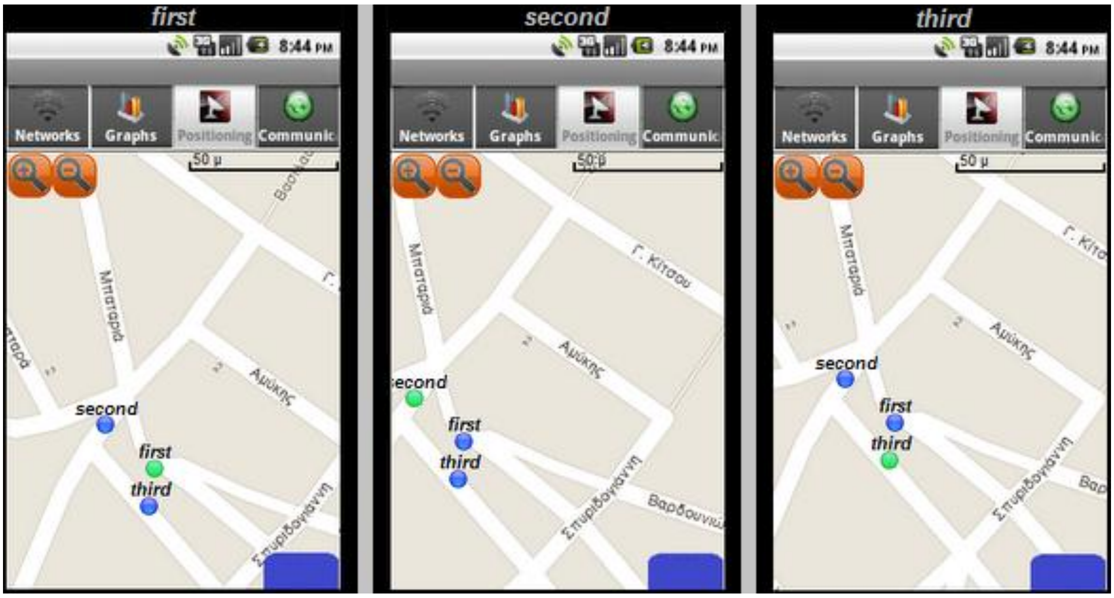

Figure 5. The devices' positions

Users share their position related opinions along with the relative PMOS scores. Each device relies on the entire exchanged information, calculates a Network-Position Score (NPS) for each available network and proposes the network along with the position which accomplishes the higher NPS. Then, the third device connects to a network. Finally, the second device connects to the internet via the third device as presented in figure 6, using the implemented mesh functionality.

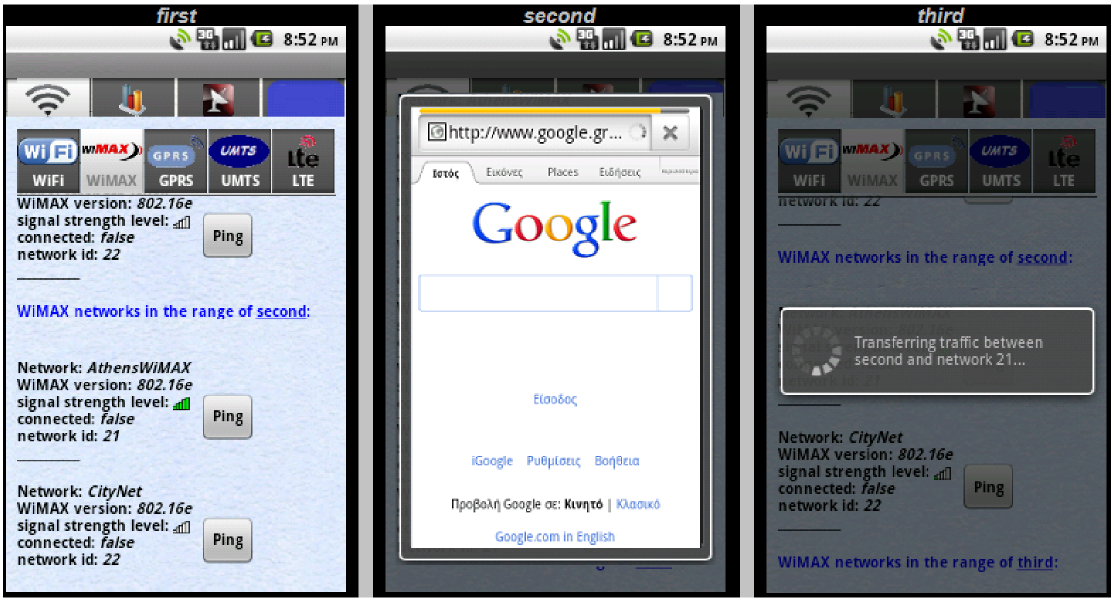

Figure 6. Application-layer mesh functionality

CONCLUSION

The proposed scheme is implemented over the Android platform. It combines technical networking information with position related users' opinions, to perform network and position proposal. A Link-16 based C3I system is constructed among the mobile devices. Each device is informed about its geographical position using GPS. Networking technical information about WiFi, WiMAX, GPRS, UMTS and LTE networks along with geographical positioning information is exchanged among the devices. Users also share their position related opinions along with relative PMOS scores. A NPS score is calculated according to the entire exchanged information and the network as well as the position which accomplishes the highest score is proposed. Finally, each Android device can connect to a network either directly or via another device using the mesh functionality.

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