Creating a Connectivity Decision Support System for Long-Term Evolution Direct (LTE Direct)

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***Abstract*—With the advent of hybrid mobile phone network architectures where handsets can act as an intermediate point as well as a source and destination for traffic, a system is needed to allow mobile users to find "connectivity". This connectivity can be in the form of a mobile network tower, or it may be another mobile user if communicating in ad hoc mode. This work builds upon the notion of a Connectivity Decision Support System (CDSS), first proposed by the author in the context of a 1G mobile network architecture. This work in progress explores Long-Term Evolution Direct (LTE Direct) and the factors related to implementing a CDSS.**

Keywords-Connectivity Decision Support System, Long-Term Evolution Direct

I. INTRODUCTION

The ability to "stay connected" with a wireless device is an important factor for mobile users both in terms of their choice of networks and also in terms of their degree of utilization of mobile devices in the first place. Areas with poor mobile network coverage are not crowded with wireless device users fighting for limited data speeds or poor call quality. This work-in-progress proposes the application of a Connectivity Decision Support System (CDSS) to Long-Term Evolution Direct (LTE Direct), an emerging standard for hybrid mobile networks. The contribution of this work is that it examines the application of a novel system for dealing with connectivity in a wireless environment, a CDSS, as a solution for providing wireless users with useful connectivity information in the context of a hybrid network architecture (LTE Direct) where mobiles nodes can act as both sources and intermediate nodes for network traffic. In section 2, previous related work is detailed including the motivation for such a system. Section 3 examines potential design aspects for a CDSS in the context of today's mobile network architectures. In section 4, LTE Direct is described in the context of the proposed system. Section 5 examines factors that must be taken into account for the development of a CDSS for LTE Direct. The final section examines the contribution and ongoing work.

II. MOTIVATION AND PREVIOUS WORK

As more and more users rely solely on their smart phones and similar wireless devices for navigation, business, and social uses, having a fast and reliable data connection (or in the case of emergencies, voice connection) are of the utmost importance. Wireless network operators do offer connectivity maps that supposedly show areas of high and low connectivity (and ranges of service), but anyone who has viewed these maps can attest to the fact that their granularity is too large for practical purposes in the context of changing positions to gain better connectivity. They only provide rough outlines of network base station coverage. Mobile network operators therefore tend to overstate their coverage in marketing their service through these graphical depictions since smaller localized factors, especially involving manmade obstacles to theoretic signal propagation, are not truly taken into account in the maps. A CDSS, therefore, would be far more useful to wireless users seeking to improve their connectivity. In the context of battlefield networks, emergency networks, and similar wireless network implementations where maintaining connectivity is critical, a CDSS becomes almost a necessity.

The author first proposed the idea of a mechanism for guiding wireless network users to areas of greater "connectivity" in 2000, prior to the advent of "smart phones" with advanced processing and memory capabilities capable of utilizing location-based information. This system, labeled a "connectivity decision support system" at the time, would vary in exact design between various types of wireless networks, but would have the main functionality of providing mobile users with connectivity measures and information about their immediate surrounding allowing them to make informed decisions regarding their location and their connectivity with respect to mobile network connection points. The general idea of such a system was further defined in a conference paper and presentation in 2003 [1] and subsequent published work in 2004 [2]. The ability to pinpoint a mobile user's location is taken for granted today; but in the year 2000, this was a novel idea that allowed for the development of many possible network services and improvements such as a CDSS.

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The author, along with his collaborators, were able to establish a mechanism for reliably predicting connectivity for 1G Advanced Mobile Phone System (AMPS) type networks where connectivity was defined as the received signal-to-noise (S/N) ratio for the mobile network handsets of the time period using neural networks [3]. The proposed crude form of a CDSS at that time relied upon S/N information collected from handsets to train a neural network to predict S/N ratios for all points on a given grid or region. Thus the collection of "connectivity" information from a select group of mobile users was used to create the knowledge base for advising all mobile users in a given region. At the time of this work, more sophisticated handsets with graphical user interfaces and advanced data networking capabilities were in their infancy.

This discussion of previous work related to the general idea of a CDSS has two goals: to introduce the reader to the concept and functionality of such a system, and to show that it was an idea ahead of its time. The 1G AMPS mobile network modeled in 2005 was at that time evolving into a 2G network architecture in most countries with more sophisticated data capabilities. The widespread implementation of more sophisticated technologies such as Digital AMPS and General Packet Radio Service (GPRS) ushered in the age of mobile applications and located-based services that are ubiquitous today. The concept of a CDSS that could be utilized for providing connectivity information to users for voice calls can have a more profound effect with respect to critical data-based applications and traffic.

III. IMPLICATIONS FOR A CDSS DESIGN TODAY

The author originally envisioned that a CDSS would have uses throughout a range of mobile network types and could be implemented in a variety of fashions. Ideally, a CDSS provides connectivity information to a wireless device user. Although the type of wireless device (and network therefore) determine the specific wireless standards utilized to create and operate the CDSS, the concept has applicability across a wide spectrum of wireless network types from 802.11x, to mobile phone networks, to ad hoc and hybrid ones. The two key operations for the creation and implementation of a CDSS are the measurement or prediction of connectivity surrounding a given wireless device user and the display of this connectivity information in a format that can be understood and quickly utilized by the user. Measuring or predicting connectivity around a given user is useless if such information cannot be readily used to decide if the user can achieve greater connectivity by changing positions or if there is a delay in the presentation of this information. By definition, the term "decision support system" represents an information system that advises, but does not make automated decisions, for a given user of the system.

It should be obvious that the implementation of a CDSS for a given network type, besides being tied to the technology involved for that network type, can vary as to its general operations with respect to the creation, storage and display of connectivity information to the user. A true handset-based CDSS would require processing and storage at the device level in order to determine connectivity, store such information, and then display it to a user. A provider-based CDSS would require that such information be determined and stored by a given network operator/provider and sent to a wireless user when requested. Also, a hybrid architecture using processing and storage capabilities both by the provider and the handset could also be used. The integration of advanced data networking capabilities in mobile phone networks has allowed for another possible hybrid architecture where a third party collects "connectivity" information from handsets (via a smart phone application) to create a connectivity database that is then accessed as requested by wireless users.

The premise of this "crowd sourced" CDSS was created by the author and a student in 2004 in a prototype website utilizing a database backend that stored S/N information (as a proxy for "connectivity") that was manually collected from a mobile handset for a grid of points around several local cellular network towers. Unlike the current smart phone applications such as OpenSignal [4] or Sensorly [5], which display connectivity measures only in areas on a map where actual information has been collected from users, the system developed by the author and his student used additional information and a algorithm to predict connectivity for all other points on the grid thus creating a complete map of anticipated connectivity for the physical region. The discussion of this previous work is to highlight one potential general design attribute for a CDSS today. Since today's cellular networks differ greatly from the analog AMPS-style networks in that several users simultaneously share a given bandwidth instead of having dedicated frequency channels, there is a need to take the "connectivity" of nearby users into account. A system that can utilize connectivity information from surrounding users and also predict such for a user as they move is a necessity in today's cellular networks. The same can be said for many other types of wireless architectures including the emerging hybrid LTE Direct standard. respect to critical data-based applications and traffic.

IV. LTE DIRECT AND CDSS IMPLICATIONS

At the time of the initial CDSS exploration, hybrid mobile networks were in use in only very specialized applications such as for battlefield networks. . A hybrid cellular network architecture would involve handsets operating both in a traditional manner where they communicate with a base station, and also in an ad hoc mode where transmissions between handsets can occur as well. A hybrid architecture would have the advantage of extending the communication range of the overall cellular network through the linking of "out-of- range" network devices with "in-range" ones to serve as intermediate relay points for transmissions. Several researchers have examined these types of networks, including Mane and Mohite [6] and Do, Hsu and Venkatasubramanian [7]. Their work is related to various topological designs, services available and operating factors for hybrid architectures. Unfortunately, such research does not address a network from a user's point of view in terms of connecting and remaining connected to such a hybrid topology. Existing work assumes users connect and disconnect from the network much the same way they do from a traditional cellular phone network base station or a Wi-Fi hotspot. This assumption can have significant implications when such hybrid networks are employed for emergency and disaster management.

The author, with his collaborators, explored the use of various types of wireless networks for disaster planning and management including such hybrid networks [8][9][10][11]. The lack of standards in the past for true hybrid cellular architectures created a costly mix of proprietary systems and less than ideal implementations of existing wireless network infrastructure for disaster scenarios. Many patents already exist that deal with some facet of hybrid cellular networks and their operation; but the creation of a true hybrid network with handsets that can forward the traffic of other handsets to existing base stations is still in its infancy. The development of the LTE Direct standards and its technologies has direct impact on the application of wireless networks for critical emergency services and serving an affected populace after a disaster.

LTE Direct promises to deliver what are known as "Proximity Services" (ProSe) in an efficient fashion much the same way as the Bluetooth standard and its associated technologies have for many years with device to device connections. Unlike Bluetooth though, LTE direct would not have the practical 10 meter limitation on transmission distance. Emerging standards for LTE Direct in 3GPP R-12 allow for ad hoc communication between mobile network handsets and devices up to several hundred meters without a severe degradation in battery life. Also included in LTE Direct's emerging standards is Device-to-Device (D2D) ad hoc communication capabilities. This functionality directly points to a need for a wireless handset user to know the "connectivity" of his or her surroundings in terms of other users within range of transmission and potential paths to the fixed network infrastructure. Some of the aspects of LTE Direct favor the use of a CDSS to maintain connections in an ad hoc fashion.

A. *LTE Direct is "Always On"*

Unlike Bluetooth which is a service that can be turned on and off for a given mobile handset, the emerging LTE Direct standard is "always on". From a practical point of view, this means that the handset running this service is always in discovery mode receiving transmissions from its environment. "LTE Direct is a new and innovative device-to-device technology that enables discovering thousands of devices and their services in the proximity of ~500 m, in a privacy sensitive and battery efficient way. This allows the discovery to be 'Always ON' and autonomous, without drastically affecting the device battery life unlike other proximity solutions such as OTT based that use GPS, or BT-LE and WiFi Direct" [12]. This aspect of LTE Direct would favor the use of a CDSS since it would always have access to signals of all similarly enabled nodes around it. In other words, the more devices a CDSS can see, the more possibilities for increasing a given measure of "connectivity" within the network.

B. *LTE Direct would allow D2D communication*

Beyond ProSe, LTE Direct promises ad hoc communications for more than location-based information and services. It promises true device to device communication that would be invaluable for disaster and emergency management. In a disaster scenario where damage to base stations (or power failures) can render cellular network connectivity nonexistent or sporadic in hard hit areas, the ability to connect directly with other LTE Direct users would provide needed support for emergency responders and the affected populace. Current 4G LTE service relies on User Equipment (UE) communicating with evolved Node B's (eNB) (4G base stations or towers) where radio resources are locally managed (as opposed to 3G services where they were more centrally controlled). LTE Direct allows for communications between both a functioning eNB or another UE or both. This scenario radically changes the nature of cellular communications in that one does not have to be within range of a functioning eNB to be able to communicate with and through the network.

D2D communication within LTE Direct would utilize the Uplink (UL) resource and also allow for channel measurements that are reported to other UE's or to the eNB [13]. This is significant with respect to a CDSS in that it provides a possible mechanism for defining "connectivity" and creating the CDSS.

V. FACTORS FOR IMPLEMENTING A CDSS FOR LTE DIRECT

This leads to the crux of the ongoing work: the examination of the factors that must be taken into account for a CDSS that would be utilized in conjunction with LTE Direct. The first of these is the tracking of locations of mobile nodes and their relationship to base stations. Much the same way the locations of current mobile devices operating on cellular networks are stored for routing purposes, an exact geographic location for each node must be maintained by the fixed architecture network. This implies that nodes not directly in contact with the fixed infrastructure base stations must report their locations on an ongoing basis through intermediate mobile nodes in an ad hoc fashion. One can see that constant location reporting will create overhead traffic for both the ad hoc and fixed parts of the network architecture.

The second major factor that must be dealt with in applying a CDSS to LTE Direct is redundancy. The reporting of location information through intermediate nodes, although being done on a periodic basis, suffers from the potential for gaps in reporting due to node mobility and reliability (nodes coming on and offline). If a CDSS is truly to provide reliable and usable information for a wireless user, it must be able to have correct information from a temporal point of view for mobile node locations. This requires redundancy in the reporting and a mechanism for ensuring that incorrect or outdated location information does not mislead the CDSS.

The third factor for a CDSS is the nature of the mobility of nodes. Within LTE Direct, D2D capabilities rely on nodes to be not only within transmission range of each other, but to have sufficient capacity and quality of signal to maintain a useful connection. The nature of mobility for each node plays a key role in this process. Transmission obstacles created by natural and manmade objects/geographic features, Rayleigh fading, and other phenomena create propagation anomalies that limit the connection between two mobile nodes. Mere physical proximity from a Euclidean distance point of view does not guarantee a useful connection for traffic. Direction and speed of a nearby node should be taken into account as well This necessitates an integration of geographic information, node mobility information and larger scale network-related information within a CDSS to provide the wireless user a true "picture" of the connectivity around him or her.

This leads to final major factor that must be dealt with, the actual measure of connectivity and how it is displayed to the user. Due to the fact that LTE Direct is a hybrid architecture, some nodes may only be operating only in D2D mode while others may also be in contact with fixed base stations. Clearly the nature of "connectivity" differs between the two modes of operation and this information must be clearly conveyed to users. One can envision a scenario where a user moves closer to a nearby mobile node under the mistaken impression that they are increasing their "connectivity" when they are actually moving away from a nearby fixed base station that would provide a more reliable connection.

VI. Contribution and Ongoing Work

As mentioned previously, this is a work-in-progress paper highlighting research by the author into applying an idea borne out of an advance in wireless handset technology (GPS chipsets in mobile devices) that originated over ten years. This paper examined key factors currently being explored in order to apply a CDSS to a hybrid mobile network architecture such as LTE Direct. Whether provided as a native feature to wireless devices enabled for LTE Direct use, or as an add-on application, the time has arrived for the functionality of a CDSS across the spectrum of wireless networks. Current work is focusing on developing the algorithmic interpretation of "connectivity" for LTE Direct and the necessary protocols for a CDSS to be utilized under this standard.

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