RRLP (LPP and LPPe) Based Open Source Mobile Multi-GNSS Assisted GNSS Assistance Model

Architecture Proposal and Test results of OSGRSv3 on LTE LBS Framework

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Abstract—**Radio resource location protocol (RRLP) was proposed by Third Generation Partnership Project (3GPP) primarily to provide efficient data transfer and network capability for applications such as Location Based Services (LBS). This is achieved by exploiting third Generation (3G) or the next generation Long Term Evolution (LTE) mobile network's Assisted, GNSS and high bandwidth capability. 3GPP LTE positioning protocol (LPP) provides the basic infrastructure roadmap for high accuracy positioning assistance model through control-plane bandwidth channels in mobile access and core communication networks. Despite its inherent capacity constraints, LPP can perform well in conjunction with Open Mobile Alliance (OMA) Secure User Plane release 3 (SUPLr3) based extension (LPPe). Combining the constrained control-plane with unconstrained user-plane bandwidth alleviates such network limitations by exploiting priority based traffic deviation. Where Secure User Plane (SUPLr1&r2) provided the positioning functionality through conventional mobile communication systems, SUPLr3 comprehensively extended the positioning parameter portfolio laying the baseline for LPPe. This paper proposes the augmented architecture of LPP and LPPe based LTE mobile network with third generation Open Source GNSS Reference Server (OSGRSv3). Interconnection of two networks is provided through IP data control gateways for information exchange according to user preferences. This expands the current Assistance Model Portfolio of Multi-GNSS OSGRSv3 and establishes its interworking criteria with several mobile communication systems involved. Current LPPe protocol, ongoing Core Network and Transmission technology evolution status are discussed with future outlook to outline reasonable design strategies for such bandwidth hungry and higher data rate applications. A real network scenario has been implemented in a controlled laboratory of a mobile carrier network environment exploiting LTE RAN, Transmission, Core and GNSS elements to test the pre-commercial launch potential of such system. Preliminary interface parameters with link performance graphs are presented. RRLP based system can potentially lower TTFF and improve availability and accuracy over its predecessor MGNSS (OSGRSv2) with LPPe enhancements by concatenating the functionality of HSGNSS, RINEX, RTCM and NTRIP. However system design is complicated and real-world operational support may further be implicated due to unforeseen parameter change in broad-baseline architecture. Logical complications could arise in multi system integration, protocol translation, network latency and traffic priorities. Nevertheless with future proof hardware architecture, OSGRSv3 could be a cost effective Multi-GNSS LBS solution for both research and industrial applications in weak signal environments such as unclear sky or indoors.**

Keywords-OSGRSv3, Multi-GNSS, RRLP, 3GPP-LPP, OMA-LPPe, SUPLr3, LTE

I. Introduction

There are a few challenges for concurrent technologies in Assisted GNSS, which means they must be capable to operate everywhere (every time and anytime) with low Time to Fix First (TTFF) in an environment agnostic or independent manner [25]. Cost ineffective commercial and proprietary protocols have interoperability and licensing issues, thus limiting independent research and academic testing potential despite known capability limitations. In some parallel processing and acquisition environments, Fourier Transforms have been proven to provide the required time and frequency domain search and processing to reduce the TTFF [23]. A classic example may be SiRFLoc, a 12 channel C/A code Assisted Global Navigation Satellite System (AGNSS) GPS chipset taking assistance information through another receiver. The technology is called Time Transfer Board (TTB) and is capable of providing initial timing and reference positioning. It exploits a Temperature Compensated Chrystal Oscillator (TCXO) to provide frequency accuracy of approximately 0.5 ppm [8].

However, accuracy and availability of stand-alone GNSS is subject to attenuation and degradation in weak signal environments, acquisition assistance is typically required [6]. A standard GNSS chipset could take approximately 60secs to compute the first position fix [8]. E911 requires time and response critical devices (e.g. LBS) to provide acquisition approximately 95 % within 150m and approximately 65% within 50m [9], which is a challenge. The assistance can be provided using alternate devices [11].

Open source GNSS reference server (OSGRS) is an open source java application that provides assistance available from local and global GNSS casters. The system has been revised over the last few years to expand the assistance model portfolio, format support capability (hardware and firmware) and improve performance (accuracy, availability & TTFF). This can be achieved by pre, partial or post-processing, assistance or acquisition through a high sensitivity GNSS receiver like Novatel OEM4 [21] or global casters [14] and Networked Transport of RTCM over Internet Protocol (NTRIP) [21]. The scheme can be categorized as Multi-GNSS Assisted GNSS capable of providing Differential GNSS and Real-Time Kinematic (RTK) cm level accuracy (Fig. 1) [21].

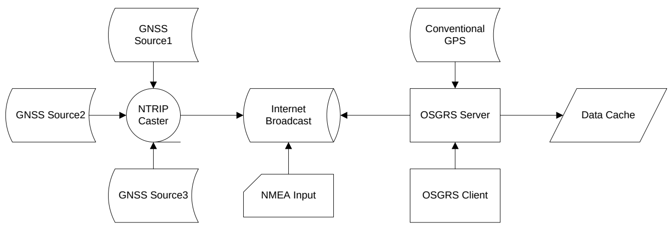

Figure 1 Assisted Multi-GNSS OSGRSv2

This paper proposes a subsequent revision of the system (OSGRSv3), which employs the enhanced capability of Radio Resource Location Protocol (RRLPr11) over mobile communication networks and the radio base transceiver stations (BTS). The expanded assistance model portfolio is presented with a real network architecture that carries GNSS and Assistance data over control and user planes of the mobile network simultaneously. Carriage performance of those channels is discussed with relative implications of the enhanced architecture.

II. Radio Resource Location Protocol (RRLP)

In mobile communications, Radio Resource Location Protocol (RRLPr11) has been proposed [1] (Release 12 in progress) for positioning in mobile GSM, EDGE, UMTS and LTE networks based on radio signals of base stations or the mobile network's GNSS hardware and software capability. Fig. 2 shows the evolution of several mobile network standards over the last decade [1], [2], [3] & [26].

GSM, GPRS	DL: 51kbps UL: 21kbps	EGPRS DL: 236 kbps UL: 118kbps	GERAN Handover	GERAN Evolution	Ongoing Evolution		
WCDMA, UMTS	WCDMA DL: 384kbps UL: 64kbps	R5 HSDPA DL: 14 Mbps UL: 384kbps	R6 HSUPA DL: 14Mbps UL: 5.7Mbps	R7 HSPA Evo DL:28.8 Mbps UL:11.5Mbps	R8 HSPA Evo DL:43.2 Mbps UL: 11.5Mbps	Ongoing Evolution	
LTE, LTEAdvanced				R7 Feasibility Study	R8 LTE/SAE DL: 100Mbps UL: 50Mbps	R9-R10 LTE	Ongoing Evolution

Figure 2 3GPP Standards Evolution

Currently, the network supports conventional GNSS (GPS L1/L2 with C/A), Galileo and other GNSS and Enhanced Observed Time Difference (E-OTD) data to be transported over control-plane channels of a radio base station (RBS) site.

The mobile network can support transfer of location information data from Serving Mobile Location Centre (SMLC), where Gateway Mobile Location Centre (GMLC) acts as the first point of interconnect with Location Communication Server (LCS) client. Fig. 3 shows the basic building blocks of a mobile network and their interconnections with respect to the Base Station (BTS), Base Station Controller (BSC), Mobile Switching Centre (MSC), SMLC and GMLC. SMLC works in conjunction with Location Measurement Unit (LMU) modules using TOA, TDOA, OTDOA or E-OTD methods. The GMLC serves as a cross-connection and translation gateway for SMLC to external location servers or clients such as OSGRS. Basic location parameters are acquired by the base station on RAN Access Network and transmitted to SMLC in Core Network for location estimation. SMLC can then work in conjunction with GMLC to acquire assistance from third party client and respond.

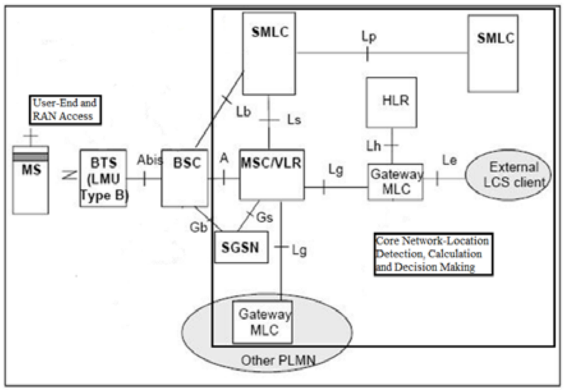

Figure 3 Mobile Communications Network

(Derivative Extract Courtesy of Creativity Software)

OSGRS data transfer takes place through TCP/IP can also be done through mobile communication channels over GSM, GPRS, EDGE, UMTS or LTE networks where sufficient bandwidth over HSPA is available. However research potential exists where transmission data latency and network availability needs to be benchmarked. Moreover, depending on the type of assistance required, this can be a bandwidth hungry application (requiring more than generic 2Mbps control channel size) and the last version of OSGRS needed software modification to support LPP data source.

Fig. 4 shows the RRLP capability matrix to provide location assistance services in a mobile communications network [3] & [24]. As the mobile transport topology of Carrier Ethernet, Multi-Protocol Label Switching (MPLS) and Internet Protocol (IP) based traffic routing become common norms of capacity expansion; associated bandwidth contention issues can be addressed further.

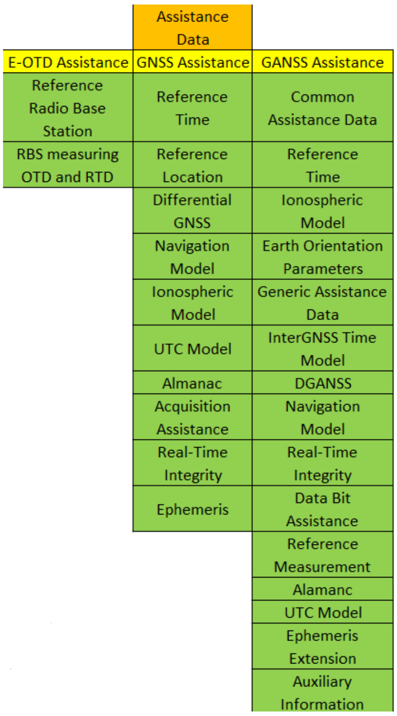

Figure 4 RRLP Assistance Model

III. Data Transmission

Several technologies for the transmission of RRLP localization data in an RAN network (GSM, EDGE, UMTS and LTE) over user and control plane protocols are available:

a. Plesiochronous Digital Hierarchy (PDH) on TCP/IP Layer-1

b. Synchronous Digital Hierarchy (SDH) on TCP/IP Layer-1

c. Ethernet over SDH (EoSDH) i.e. TCP/IP Hybrid Translated Interconnection of Layer-1 and Layer-2

d. Carrier class Ethernet (CE) on TCP/IP Layer-2

e. Multiprotocol Label Switching (MPLS) or IP on TCP/IP Layer-3.

Two types of information transfer modes have been proposed for AGNSS and/or Assisted Galileo and Additional Navigation Satellite Systems (AGANSS) data transmission and signaling information, with their respective advantages and disadvantages. They are as follows:

A. Control Plane or Back-Plane

This is an integral part of a Radio Access Network (RAN) to carry signaling, integration, control and access information. Obviously maintaining the integrity and security of information efficiently is capacity constrained and is limited to carry only bare minimum or just necessary information, which is the reason it's predominantly used to carry LPP information that is discussed in detail in next section. Common examples are E911 (e.g. distress rescue operations), LBS (e.g. GNSS Assistance and/or Correction), law enforcement (e.g. Police calls) and network monitoring and/or control. As an example, Short Messaging Service (SMS) was originally established for emergency and network control operations and has previously been proposed as a backup for transferring data on mobile phone networks in assisted Global Navigation Satellite Systems and location based services. SMS, location and control information flows through control plane and SMSC, which has limited bandwidth (~ 2Mbps) and is subject to arbitrary blockage or latency in real-time.

Character limitation per channel can be another issue if the assistance data exceeds the limit allowed by mobile phone carriers. This can leave the end user in distress, with compromised message delivery confirmation. This can be due to Mobile Number Portability, MNP, network congestion, Short Messaging Service Centre, SMSC faults, inconsistent network (Building Integrated Timing Supply (BITS)) clock syncs in Time Division Multiplexed, TDM or Ethernet networks and incompatible software or hardware architecture at end clients. In the case of mobile transmission (PDH or SDH mode) layer, generic out of band control channels are 2Mbps bandwidth per mobile base station site. Channel Contention can't be completely resolved even after the standard mobile transmission networks transition to carrier Ethernet level due to various factors and traffic deviation will be required to channel control and user data appropriately. For effective usage of control plane, this bandwidth will need to be 'feedback router optimized' or enhanced, which isn't a cost effective method. Rather, enhancement of user plane bandwidth is considered feasible as it serves generic traffic capacity expansion purpose as well.

B. User Plane or Front-Plane

User plane signaling, on the other hand, is well established on call and data channels running on layer 2 or layer 3 channels. However with higher bandwidth and the potential to carry bandwidth heavy control and payload information, it has potential issues with security and integrity. For most non-emergency, Value-Added Services (VAS), charging, roaming and GNSS Assistance information carriage, user-plane is the default channel of choice. Mobile communication over internet protocol (MoIP) can be a cost effective alternative. Universal Mobile Telecommunication Systems (UMTS), Worldwide Interoperable Microwave Access (WiMAX) or Long Term Evolution (LTE) networks are being deployed globally and will soon be available for high data rate communication of approximately 100Mbps or higher using pre-installed Mobile communication over IP or more common MoIP clients on mobile phones.

Benefits include relieving the control-plane, in lieu of using relatively resource abundant data channels for effective throughput for assisted GNSS data transfer applications. Secure User Plane Location (SUPL) also proposes to exploit user plane for data transfer, which has broader bandwidth. Considering the cost-effectiveness, many operators are considering the use of user-plane to carry GNSS enhancement/Assistance data as it can work over data connection on a 3G network [24]. Many devices globally have this capability e.g. MiO A701 uses SUPLr1.0. However the protocol will struggle where mobile coverage is unavailable or more specifically, were poor in-building coverage in the absence of appropriate repeaters systems, which generally are not cost-effective. End-user location is estimated with the signal strength knowledge of RBS, where location accuracy is subject to coverage. Location is calculated in the core network by SMLC, where GMLC interconnects with the external location server. SUPL standard has been proposed (OMA, 2007) to specify the requirements of traffic carried over user-plane and the standard has been revised three times since its inception. SUPLr3 (2011) is the latest version based on first release (TCP/IP) and second release (geographic and temporal triggers) hence specifying the streaming requirements for LPPe assistance data with WLAN and local assistance data servers such as OSGRSv3.

IV. LTE Positioning Protocol (LPP) and LPP Extensions (LPPe)

LPP was proposed to carry the bare minimum GNSS parameters on LTE control-plane of LTE (3.9G) and LTE advanced (4G) networks. It is an AGNSS, ECID and OTDOA self-contained protocol to provide basic GNSS services for emergencies and law enforcement services (3GPP, 2009). The protocol predominantly employs RRLP based RAN network cell localization methods in GSM, W/CDMA, UMTS or LTE networks. It utilizes one or a combination of following transceived (Tx/Rx) signal characteristics for location determination of a mobile user:

a. Enhanced Cell ID (ECID)

b. Base station position and Transmit power

d. Round Trip Time (RTT)

e. Antenna gain and Azimuth,

g. Beam width and Frequency drift

By employing one or a combination of the above, following techniques can be used for location estimation:

a. Time Difference of Arrival (TDOA)

b. Cell Identification Methods

c. Enhanced Observed Time Difference (E-OTD)

d. Observed Time Difference of Arrival (OTDOA) measures through a hyperbola along which the end-user may be calculated.

e. Database and Pilot Correlation

g. OTDOA Idle Period Downlink (IPDL)

With their respective advantages and disadvantages, TDOA, TOA, RTT and Pilot Correlation are some common methods. To understand one case for instance; RTT is used to evaluate the distance between the RBS and end-user where the values are high for UMTS [24]. A subset or superset can be created using the RTT values from neighboring RBS. Location estimation using Cell ID using Timing Advance and RTT from RBS using the Hand-Over procedure [5]:

$$F(x) = \sum_{i=1}^{N} f_i^2(x) - P\sum_{i=1}^{N}\left[\frac{1}{g_i(x)}\right]^{-1} \tag{1}$$

where

$$g_i(x) = -t_i(x)$$

and

$$f_i(x) = d_i - \sqrt{(x_i - x)^2 + (y_i - y)^2} \geq 0 \tag{2}$$

Where x is the superset column matrix of MS (x, y) and P is a positive scalar quantity. Hence, location detection is evaluated using the following recursion

$$x_{k+1} = x_k - \mu \nabla_x F(x_k) \tag{3}$$

Until the following condition is met for a pre-specified threshold:

$$\|\nabla_x F(x_k)\| \leq t \tag{4}$$

Pilot correlation is based on database repository of Received Signal Strength and measurements of available code pilots. Where the geographic geometry of area of interest is segregated into regions based on cached Received Common Channel Pilots. Location estimation is carried out based on comparative Least Square Method:

$$S_{LMS} = \sum_{i \in N}(S_i - m_i)^2 = \sum_{i \in N}\Delta_i \tag{5}$$

Where Si is the value of iterative code sample to be stored, mi is the value of iterative measurement of sample and N is the number of vector fields. Hence location is estimated in the proximity of point of intersection and smallest SLMS.

LPP extension containers were proposed to support the future development of protocol without drastically changing the LPP and hence to avoid overloading the control channel, which cannot be expanded cost efficiently. The first extension LPPer1 was released in 2010 [16] and a candidate release proposed for approval [16] with standardization expected to finalize soon.

It is important to understand some primary enhancements in SUPLr3 assistance data for specific applications. In OMA LPPe Release Candidate (RC), the field 'AGNSS-CCPassistCommonProvide' is mandatory (with some optional parameters like support area, reference station list, neighbor area etc.) in requesting basic information as Continuous Carrier Phase Assistance to provide mm level accuracy positioning of target device. Alongside, the parameter 'phaseRangeRMSerror' for RMS error in carrier phase and 'lockIndicator' which is true if tracking has been continuous and false if it's broken or a cycle slips. Support is being made available for a variety of GNSS systems as not all end systems have been finalized to work with LPPe. Mobile operators and/or vendors globally will need some time to develop and mature their technology to support and/or exploit the full-scope functionality of LPPe. Future developments may say some levels of variations in LPPe protocol assistance models from different vendors. Hence varying sets of network Key Performance Indicators (KPI) and operator Service Level Agreements (SLA) could be established despite much speculated LBS and AGNSS standardization efforts. For details of LPPe assistance model portfolio, its comparison with succeeding and preceding location estimation and assistance models (LPP and SUPLr1/2) and understanding the integration lifecycle with OSGRS (Table 1).

In addition to new LPPe methods like handshake establishment routines and assistance procedures, the protocol also includes additional information elements such as:

a. Validity area parameters and Ionospheric storm indications (including wide area correction surface parameters)

c. Tropospheric delay models (Zenith delays to target altitudes (Gradient parameters), mapping function)

d. Satellite body-fixed coordinate frame

e. Navigation degradation models (e.g. clock model or orbit model) and Solar radiation pressures

g. CRC16-IBM and Antenna information (reference frame, Euler angles)

i. Basic AGNSS and Enhanced Cell ID

k. Hyperbolic Time Based Methods

l. Real-Time Kinematics (RTK) and Precise Point Positioning (PPT)

The above set of information therefore represents a preliminary step in standardizing indoor-capable positioning methods.

This endeavors to bring all the non-standard and standard technologies beneath the framework (GNSS, AGNSS and AGANSS) and utilize the potential of professional-grade GNSS to the consumer market which includes:

a. Carrier Phase Methods (Continuous and Non-continuous)

b. Higher Accuracy with multiple reference stations

c. End-user and reference station flexibility and mobility

d. Mechanisms of session control

e. Periodic Tropospheric and Ionospheric corrections

f. Meteorological and Weather Information, Broadcast and Warning

g. Mapping and Altitude Data

h. Quick Time to Fix First (TTFF) with Additional Hardware Support

i. Navigation Model Degradation Information in Real-Time

j. Differential Locking and Code Biasing for Higher Accuracy

Long term evolution, LTE positioning protocol, LPP r1.0 is predicted to provision high availability and accuracy due to high user-plane bandwidth however challenge exists where this technology hasn't been deployed and tested. This paper addresses this by employing basic LTE based LPP and LPPe architecture for acquisition and assistance provisioning through integration with OSGRS. Secure user plan, SUPL r3.0 also expects to expand the communication capability on the basis of LPP. Literature review is also recommended for viability assessment of time and effort investment of such methods for academia and industry once the all protocols are finalized or reach RC stage. LPPe can support non-cellular positioning methods such as:

a. Wireless LAN and Wireless Beacon Nodes

b. Location detection can be based on Transmit, Receive power

c. Round Trip Time (RTT) based methods

d. Indoor and undercover specific nodes and methods

e. Unspecified or arbitrary geometrical area

f. Radio Frequency Identifier (RFID) and Bluetooth Nodes

g. Mobility specific End-User Nodes

Table 1 outlines the Assistance Model of OSGRSv1 & 2 and compares their capability against OSGRSv3 - which is based on 3GPP LPP and OMA LPPe integration. A total of 26 assistance data types have been listed in the left most column. The assistance data available through OSGRSv2 are depicted by green highlights. Here, the character 'Y' which stands for 'YES' means the respective data is available.

The assistance data types available through OSGRSv3 have been depicted by yellow highlights. This represents vast improvement over OSGRSv2 in terms assistance data set availability through OSGRSv3. The underlying integration model constituting such capability set is presented in Fig. 5, Section V.

The table also baselines the network architecture design requirements, capability specifications and lays necessary performance metrics of the proposed OSGRSv3 thus acquiring assistance GNSS data through LPP and LPPe protocols.

Table1. Assistance Model Overview

MultiGNSS Assistance Model							
		OSGRS					
		OSGRSv1		Multi GNSS-OSGRSv2	3GPP/OMA & OSGRSv3		
						LTE	SUPL-R3
P.No.	Assistance Data	All Statellites	Satellites in View		SUPL-R1/2	RRLP LPP	LPPe
1	Navigation Model (Generic (G), Specific (S))	Y	Y	Y	N	Y	Y
2	UTC, RTI	Y	RTI	Y	Y	N	N
3	Ionospheric & Atmospheric Model	Y	N	Y	Y	Y	Y
4	Acquisition Assistance	N	Y	Y	N	N	N
5	Alamanc	Y	Y	Y	Y	Y	Y
6	Reference Time	Y	Y	Y	N	Y	Y
7	DGNSS	N	Y	Y	N	Y	Y
8	RTCM Support	N	N	Y	N	N	N
9	RINEX Support	N	N	Y	N	N	N
10	NMEA Support	N	N	Y	N	N	N
11	Multiprotocol Support	N	N	Y	N	N	N
12	Authentication	N	N	Y	N	Y	Y
13	Authorization	N	N	Y	N	Y	Y
14	Mount Point Info	N	N	Y	N	Y	Y
15	Format RFC	N	N	Y	N	N	N
16	Carrier Info	N	Y	Y	N	Y	Y
17	Compression and Bit Rate Info	N	N	Y	N	N	N
18	GPS TOW Assist (Sat.ID, Anti Spoof, Alerts, LBS)	N	N	N	N	Y	N
19	Multi Network Support (GPS, GNSS, GSM, UMTS)	GPS	GPS	GNSS	N	Y	Y
20	Cell Positioning Methods (OTDOA, O/TOA, E/OTD, GNSS)	N	N	N	N	Y	Y
	OTDOA, E/OTD Reference Cell Info	N	N	N	N	Y	Y
	Neighbour Cell Info	N	N	N	N	Y	Y
	Signal Measurement Info	N	N	N	N	Y	Y
	Measurement Quality	N	N	N	N	Y	Y
	Capability List Provisioning	N	N	Y	N	Y	Y
	Error Lists	N	N	N	N	Y	Y
	Target Device Errors	N	N	N	N	Y	Y
	Location Server Errors	N	N	Y	N	Y	Y
	Enhanced Cell ID Positioning	N	N	N	N	Y	Y
	Network Time (GNSS, GPS, GSM, UMTS)	N	N	N	N	Y	Y
22	GNSS Reference Location	N	N	N	N	Y	Y
	Klobucher Model	N	N	N	N	Y	Y
	NE Quick Model	N	N	N	N	Y	Y
	Earth Orientation	N	N	N	N	Y	Y
	Time, Model List	N	N	N	N	Y	Y
23	Standard Clock Model (NAV, CNAV, GLONASS, SBAS)	N	N	N	N	Y	Y
	CNAV-ECEF	N	N	N	N	Y	Y
	GLONASS-ECEF	N	N	N	N	Y	Y
	SBAS-ECEF	N	N	N	N	Y	Y
	Navigation Model (Keplerian Set (Normal, REduced)) NAV, CNAV, GLONASS, SBAS	N	N	N	N	Y	Y
	GNSS Alamanc	N	N	N		Y	Y
	GNSS UTC	N	N	Y	N	Y	Y
	GNSS Realtime Integrity	N	N	N	N	Y	Y
	GNSS Data Bit Assistance	N	N	N	N	Y	Y
	Auxiliary Info (Sat. ID, Health, Channel)	N	N	N	N	Y	Y
24	SUPL Roaming Function	N	N	N	Y	Y	Y
	OTDOA over LTE	N	N	N	N	Y	Y
	Privacy Function	N	N	N	Y	N	Y
	Security Function	N	N	N	Y	N	Y
	Roaming Support Function	N	N	N	Y	N	Y
	Charging/Billing	N	N	N	Y	N	Y
	Service Management	N	N	N	Y	N	Y
	Triggering	N	N	N	N	N	Y
	Position Calculation	N	N	N	N	N	Y
	Altitude Performance	N	N	N	N	N	Y
	High Accuracy Relative Positioning	N	N	N	N	N	Y
	Indoor Performance	N	N	N	N	N	Y
	Cable, DSL, LAN Interworking	N	N	N	N	N	Y
	Wireless, Wifi/WLAN Support	N	N	Y	N	N	Y
	Data Integrity and Confidentiality	N	N	Y	N	N	Y
25	Sensitivity (Coarse Time, Fine Time)	N	N	Y	N	Y	Y
	Dynamic Range	N	N	Y	N	Y	Y
	Multipath	N	N	N	N	Y	Y
	Moving Scenario	N	N	N	N	Y	Y
	Periodic Update	N	N	N	N	Y	Y
26	Constraints Handling	N	N	N	N	N	N
	Frequency Errors Handling	N	N	N	N	N	N
	Atmoshpheric Errors Handling	N	N	N	N	N	N
	GNSS Errors Handling	N	N	N	N	N	N
	Timing Errors Handling	N	N	N	N	N	N
	Adaptive White Gausian Noise Handling	N	N	N	N	N	N

V. INTEGRATED ARCHITECTURE (3GPP LPP, OMA LPPE AND OSGRSV3

This paper proposes and tests the combination of 3GPP LPP, LPPe and OSGRS to enhance the OSGRS's Assistance Model portfolio. Such scheme will provide the benefits of locally connected GNSS hardware, globally available GNSS casters, modern RRLP based mobile phone positioning and third party assistance servers available through LPP extension protocol for a next generation assistance model architecture. This arrangement of several positioning and assistance systems could potentially be a fail-safe GNSS assistance system that can be categorized as a Multi-GNSS Assisted GNSS, which can provide differential GNSS and Real-Time Kinematic (RTK) assistance up to cm level accuracy. It can provide also provide GNSS correctional functionality to IP or LTE networks. The system (MS Based or MS Assisted) can support text, RTCM, RINEX or ASCII formats and can operate without the limitations of Virtual Private Network (VPN) in a flexible client-server manner exploiting locally and globally available GNSS data sources. Fig. 5 shows overall integrated architecture of Multi-GNSS Assisted GNSS OSGRSv3 system. Fundamentally the 'OSGRS side' is similar to the one shown in Fig. 1 with cross-connection capability to IP network and interfaces to Wireless and SMS gateways.

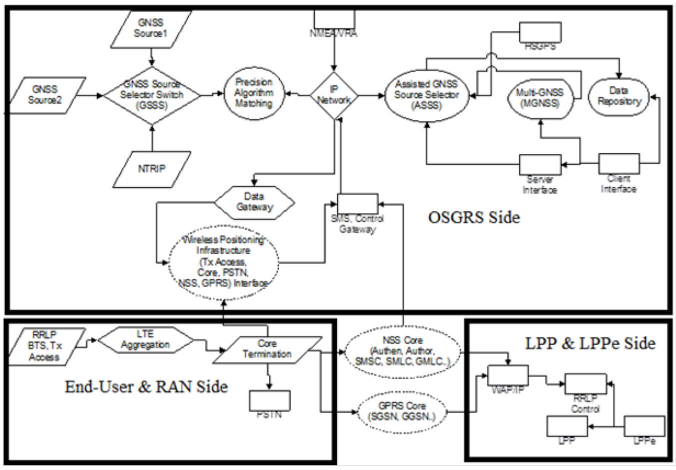

Figure 5 OSGRSv3 Architecture

The LPP works in conjunction with LPPe to provide the user specific Assistance through the generic mobile communication positioning system i.e. RRLP module, which henceforth interfaces with the WAP server. On the lower left-hand side is the end-user air-interface system through the BTS. The end-user can flexibly connect through the BTS system or OSGRS user interface to request specific GNSS or assistance data from the system of choice. Generally AGNSS processing can take place on coupled machines to achieve optimum acquisition of generic or specific data and calculation performance of client requests. Client-server based architecture means the client could be a mobile or fixed AGNSS system requesting assistance through any mobile or IP connected network.

VI. EXPERIMENTATION

It is important to understand the effects of attenuation when signals are subject to different materials. For example indoors, L1 = 1500 MHz signals would experience different levels of attenuation (dB) when subject to different materials. A drywall, glass or plywood can cause much lower attenuation e.g. 1-3dB. On the other hand bricks and concrete can cause attenuations levels ranging between 5-33dB. Similarly the attenuation in buildings is 5-15dB for residential houses, 20-30dB for office buildings >30dB for underground car parks and tunnels [13]. In the absence of an inherent high bandwidth mobile communication system that is based on end to end Carrier Ethernet and IP technologies, the establishment of full-scope network functionality is not the scope of this paper. While both Tier 1 and Tier 2 carriers are trying to upgrade the network capability, we established the practical configuration with available components of next generation networks.

Fig. 6 shows the conceptual connectivity diagram of a next generation mobile network components used to provide A/GNSS functionality. The test environment was established in a mobile network exchange connecting major RAN and Transmission network components. Once the appropriate parameters are selected on the Graphical User Interface (GUI), the OSGRS sends the request through mobile network's IP or HSPA gateway to LPP and LPPe servers connected to SMLC. The mobile network then responds with the appropriate GNSS parameters or sends GNSS error response. Tests were conducted using two data transmission topologies in the test environment i.e. Carrier Ethernet and SDH

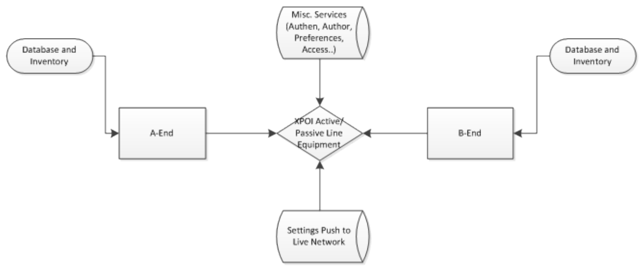

Figure 6 Conceptual Connectivity Diagram

A. LTE RAN and Layer 2 Carrier Class Ethernet Transmission

The above configuration was setup using LTE RAN and Gigabit Ethernet (GE) Transmission channel where Huawei and Ericsson devices were used for the high capacity link establishment and interface connectivity. The interface card was GE named EX2 and the underlying link was 10Gigabit Full Duplex Ethernet LAN. The link successfully provided LPP GNSS throughput on layer 2 transmission protocol through the RAN network.

The following graphs (Fig.(s) 7 a & b) show the 24hr and 15min interval performances of the GNSS throughput. In a 15min interval no localization throughput errors were experienced for duration of data transmission demonstrated by the red line whereas some intermittent errors are shown by the blue line during a 24hr interval however with overall successful throughput. This can be due to many factors such as inconsistent air interface, erroneous cross connecting data links, faulty RBS or problematic microwave or fiber mediums. Nevertheless within range inconsistent optical noise level variation in connectivity doesn't mean unsuccessful throughput. To realize the full scale effects of this variation on performance, more specific testing needs to be designed.

Figure 7a. 24hours

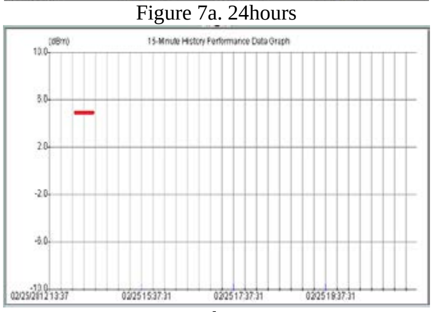

Figure 7b.15mins

B. LTE RAN and Layer 1 Synchronous Digital Hierarchy Transmission

The second scenario was established using LTE RAN RBS and Layer 1 Synchronous Digital Hierarchy technology where Ericsson devices were used to established the link connectivity on LTE and conventional SDH technology. The OSS user-end shows some inconsistent data rate input from SMLC which is demonstrated by Unavailable Seconds (UAS) errors (Fig. 8) with only leakage throughput.

Current

Elapsed	Processing type	BBE	ES	SES	UAS	SUEC	SDF	RI
00:05:49	Maintenance based	0	0	0	349	0		*

Historic

End time	Processing type	BBE	ES	SES	UAS	SUEC	SDF	RI
10/03/2012 9:45:00 AM	Maintenance based	0	0	0	900	0		
10/03/2012 9:30:00 AM	Maintenance based	0	0	0	900	0		
10/03/2012 9:15:00 AM	Maintenance based	0	0	0	900	0		
10/03/2012 9:00:00 AM	Maintenance based	0	0	0	900	0		

Figure 8 Performance Statistics Summary

This can be due to bandwidth mismatch on transmit or receive ends or logical or physical link failure. Overall results indicated optical signal levels between the ranges of ~ ±3-5dBm with successful transmission, which is generally acceptable for carrier grade networks.

VII. CLOCKING AND OPERATIONAL SUPPORT SYSTEMS (OSS)

Clocking and timing synchronization source was selected to provide GNSS assistance and achieve sustainable performance objectives of SMLC throughput to cater for potential LPP and LPPe Jitter and Wander considerations. Following clock sources are available for network and device synchronization.

a. G811 standard PTP 1588v2 (internal/external hybrid source)
b. G813 SDH (internal source)
c. G907 (internal source)
d. G811 GNSS (internal/external hybrid source)

For our experiment, network clock was used to start-with and followed by later isolation of test environment. The logical control channel running provides separate GPS clocking (Clock Class ~ 6) with an accuracy of ~ 25ns for SMLC information throughput to be transferred to end equipment. Alternatively other Building Integrated Timing Supply (BITS) clocks adhering to 1588/v2 protocol can be chosen such as Atomic, Terrestrial Radio, Precision Time Protocol (PTP), Network Time Protocol (NTP), User Handset or Internal Oscillator.

The vital importance of understanding the value of next generation OSS systems cannot be overlooked for such type of integration and experimentation. Vendor specific Operational Support Systems are used for interfacing with mobile network devices. They provide a Command Line Interface (CLI) or Graphical User Interface to allow the network operator to access and push the desired preferences, connectivity and functions specific to the device e.g. Manage user-end services, Network element interface, Remote Network Management, Network Monitoring, Capacity Management, Link Management, Fault Management, Fault Remediation and/or Physical Access and Authorization. Fig. 9 shows building blocks of the operational support system used to implement the presented configuration.

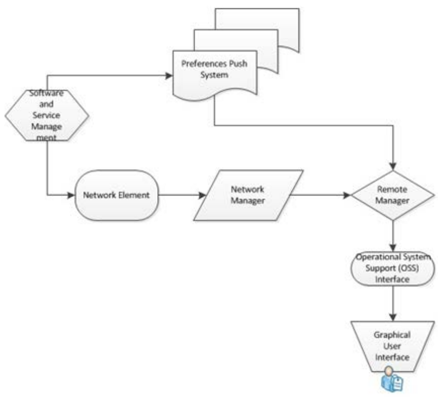

Figure 9 Building Blocks of an Operational Support System

VIII. PERFORMANCE METRICS

The OSGRSv2 and v3 performance(s) were gauged against following performance metrics, which are translated from the combination of initialization, protocol translation, system concatenation and transmission latency.

a) Satellite Visibility
b) Time to Fix First (TTFF)
c) Accuracy
d) Availability

It is important to describe here that specific first integration OSGRSv2 tests have been presented in [20] - however tested in different scenario; whereas the tests presented in this paper have been conducted in a controlled carrier laboratory environment.

Fig. 10 demonstrates that OSGRSv2 tracked ~ 10 satellites where OSGRSv3 tracked ~14. OSGRSv3 demonstrated improvements in TTFF by ~ 0.3s, availability by 0.001% and accuracy by 0.4m over the predecessor OSGRSv2. Despite the improved performance, the depicted failure rates of two systems in comparison have been marginal.

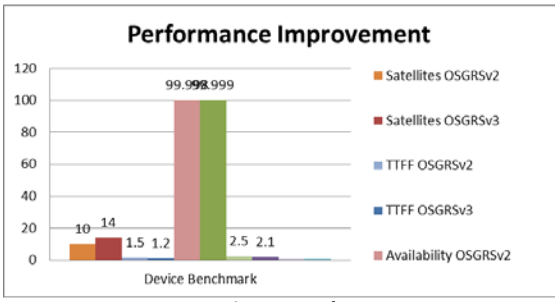

Figure 10 Test Results

IX. COMMENTS AND FUTURE WORK

The prime focus of this proposal is to advance towards testing of LPP and LPPe based OSGRS and establish performance potential based on empirical data. This would help to standardize the system, where AGNSS, Enhanced Cell ID and TDOA methods fall under the same umbrella. SUPL3.0 and LPPe1.x support standardization of third party devices to augment the functionality of LPP. This is a major advance in the field of AGNSS and AGANSS and may require some time to achieve network maturity and technology evolution for widespread or global adoption. The essential network layer amendments to provision the presented configuration and its comparison against the OSI layer are out of scope for this paper due to space constraints – however are necessary considerations for the system respective to the relevant application.

Logical complications could arise in multi system integration, protocol translation, coding rates, throughput mismatch, physical factors, environmental factors, microwave interference, network latency and traffic priorities, thus effecting link performance in a complicated system of systems. HSPA bandwidth on user-plane addresses transport latency and deals with complications in network architecture to some extent by providing data correction capability. OSGRS cannot only receive input from LPP and LPPe channels integrated into the mobile core network, but can also act as an LPPe system directly or TCP/IP connected with conventional Mobile, UMTS or LTE networks, provided that user or control plane bandwidth is available. RRLP capable OSGRS has been proposed to provide assistance information on wider throughput channels from Service Mobile Location Centre (SMLC), with Gateway Mobile Location Centre (GMLC) being the first point of interconnection with the Location Communication Server (LCS). However indoor fading, ranging, arbitrary cell geometry or hexagon can effect penetration and coverage footprint of carriers.

This next generation network scenario has been implemented in tested in the laboratory for successful throughput and preliminary performance checks on available bandwidth to support the OSGRS acquisition functions through LPP. However, such capability isn't widespread in mobile communication networks, as it requires more bandwidth that carrier Ethernet or MPLS transport protocols (IETF RFC4842) can provide in order to fully exploit the LPP data source for RRLP. LPPr1.x is proposed to provide higher performance (availability and accuracy [25]) subject to higher user-plane bandwidth however most commercial networks need to be designed, deployed and tested beforehand. A backup solution in the absence of in-building coverage (IBC) repeaters is yet to be proposed. Future enhancement proposal could see Wireless Sensor Networks being integrated into OSGRS to step-up the system's capability to provide more personalized or localized assistance data independent of conventional GNSS hardware and mains power.

Future developments may see some levels of variations in LPPe protocol assistance models from different vendors. Hence varying sets of network Key Performance Indicators (KPI) and operator Service Level Agreements (SLA) could be established despite much speculated LBS and AGNSS standardization efforts.

The paper does appreciate the fact that more specific testing needs to designed, established and conducted before full-scale or commercial launch. Such testing may or may not consider isolation of separate Access, RAN, Aggregation, Transmission, Core or XPOI elements to pin-point the bottlenecks and limitations. However this is pending commercial level investment due to complexity, size and scale of equipment involved and licensing needed. The system could help alleviate GPS and peer search errors, noise errors, inherent problems of time sync errors, node broadcast errors, internode synch errors and system connectivity repairing assistance [21] inherent to some systems. Nevertheless OSGRS has proven to provide better indoor availability, flexibility, low TTFF and higher sensitivity. Commercial applications can include use in crime prevention; emergency and incidence respond management, product tracking at industrial sites, wildlife habitat monitoring, home control in addition to location based services and advertising, user guidance, communication network routing and asset tracking, etc.

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