Global WSN Developments: Fractal or Chaos?

Oludare Olorunniwo[1], L.O. Kehinde[1], M.A. Olorunniwo[2]
[1]Department of Electronic and Electrical Engineering, Obafemi Awolowo University, Nigeria
[2]Department of Geology, Obafemi Awolowo University, Nigeria

Abstract--**The ubiquitous developments of wireless sensor networks (WSNs) for data acquisition have migrated significantly over time from traditional data networks to real-time distributed network for sensor data fusion. However, the fractal geometry of sensor distributions and chaotic dynamics of WSNs have questioned the programmability techniques, computational capability, energy-efficiency and fault tolerance, positioning and location management of current frameworks in WSN applications. Thus, this study presents the status quo and visions of the next-generation WSN technologies, the self-similarity in efficient WSNs for topology control, and the observed pattern recognition in acquired data—toward achieving efficient data distribution.**

I. WIRELESS SENSOR TECHNOLOGY: THE STATUS QUO

The repertoire of wireless technologies has transcended the exceptional epoch of developmental stage. Pointedly, WSN provides an effective approach to wireless data communication or links between devices and network nodes. From satellite communication to terrestrial microwave, cellular or mobile networks and personal communication service (PCS), wireless sensor technologies have applications in mobile communication, environmental monitoring, disaster detection and mitigation, healthcare, oil and gas, transport and logistics, mapping, tracking and geographic positioning, location-based services (LBS), Wi-Fi local area networking —to mention a few. The Institute of Electrical and Electronics Engineers (IEEE) has developed and maintained a group of wired and wireless standards for a variety of applications. Understandably, based on IEEE802.11 platforms, collaborative efforts in wireless sensor technologies have proffered diverse solutions: The main concept and architecture are directed toward security, autonomous deployment of sensor nodes, reliability, intelligence, flexibility, and energy efficiency [1]. Despite susceptibility to interference, the 802.11 'family' has provided a set of media access control (MAC) and physical layer (PHY) specifications of implementing wireless local area network (WLAN) in the 2.4-2.5GHz, 4.915-5.825GHz, and 60GHz spectra bands (the most popular is defined by 802.11b/g protocols), sustained by the IEEE LAN/MAN Standards Committee (IEEE 802) . Table1 is a summary of developments of 802.11 technologies by task groups (TG) between 1997 and 2014[2]-[4].

Notably, in June 2003, the IEEE802.11g-2003 specification was endorsed by the U.S. Federal Communication Commission (FCC) based on orthogonal frequency-division multiplexing (OFDM) design—a modulation technique that enabled wireless data transmission of about 54Mbps in the 2.4GHz band on the industrial, scientific, and medical (ISM) spectrum. Though rapidly adopted, the standard with full backward compatibility with the 802.11b specifications was yet to amend the interference issues with paraphernalia operating in the 2.4GHz. Consequently, on March 2007, the base standard IEEE 802.11-2007 by Task Group ma (TGma) was approved; this was a modification of enhancements, extensions, and procedures of 802.11a, b, d, e, g, h, i and j of the 1999 version of the 802.11 standard. Further, on September 2009, the IEEE Standard Association approved the IEEE 802.11n-2009 specification, an amendment with additional multiple-input multiple-output (MIMO) antenna features. Though 802.11n operates both on the 2.4 and 5GHz—maximum data rate ranges from 54 to 600 Mbps— it is still to be completely ratified. Currently, the IEEE 802.11-2012 standard developed by TGmb was published in March 29, 2012. The new standard is an agglomeration of 10 amendments (802.11k, r, y, n, w, p, z, v, u, and s) with IEEE802.11-2007 specification. Moreover, the IEEE 802.11ac and ad ('WiGig') under developments are standards which would enable WLAN higher throughputs, above 1Gbps to a theoretical maximum of 7Gbps in the 5GHz and 60GHz respectively, using high-density modulation techniques, multi-user MIMO, and wider RF bandwidth. Migrations and expansions into 802.11ac specifications by industrial hardware manufacturers are expected in early 2014[5]-[7].

Significantly, global wireless sensor network market grew 10-fold from 2007 to 2010 and exceeded 45 million annual shipments in 2011. Figure 1a shows the trend of global WSN market between 2010 and 2014. Similarly, the global wireless health marketplace is on a trend to reach $38.51 billion by 2016, at a compound annual growth rate (CAGR) of 19.43% from 2011 to 2016 [8]. Simply put, the evolving WSN market is approaching a converging apex where competing technology standards, forces and trends of market sizes, interdependencies of competitors, applications and scenarios would dictate the next revolutionary time frame. To illustrate, the Radio Frequency Identification (RFID) technology sector has increased from $6.98 billion in 2012 to $7.88 in 2013, with an expected growth to $9.2 billion in 2014, and a market projection to $23.4billion by 2020 (Figure 1b).

TABLE 1. THE DEVELOPMENTS OF IEEE 802.11 NETWORK AMENDMENTS AND STANDARDS

Developments of IEEE 802.11 Network Standards							
802.11 Protocols	Definition	Date of Release	Frequency Band(GHz)	Range of Data Rate(Mbps)	Modulation Technique	Approximate Range	
						Indoor (m)	Outdoor (m)
Legacy	The original WLAN standard	June, 1997	2.4	1-2	DSSS	20	100
a	Enhancement to 802.11; supports 54Mbps at 5.8GHz using Orthogonal Frequency-Division Multiplexing.	September, 1999	3.7/5	6-54	OFDM	35	120-5000
b	Enhancement to 802.11; support 5.5 and 11Mbps.	September, 1999	2.4	1-11	DSSS	35	140
g	Enhancement to 802.11; supports 54Mbps at 2.4GHz, backward compatibility with 802.11b.	June, 2003	2.4	6-54	DSSS, OFDM	38	250
n	Enhancement to 802.11; support higher throughputs using multiple input, multiple output (MIMO) antennas.	September, 2009	2.4/5	7.2-72.2/15-150	OFDM	70	250
ac	Enhancement to 802.11n; support higher throughputs over 5GHz, advanced modulation technique, higher channel capacity using (MIMO) antennas.	In process, December, 2012	5	87.6-866.7	OFDM	-	-
ad	WiGig; the new standard to achieve a theoretical throughput up to 7Gbps at 60GHz.	Pending, February, 2014	2.4/5/60	6912	-	-	-

RFID systems is a collection of small transponders, or *tags* attached to physical objects, which respond to RFID transceivers or *readers* with some attributes associated with arbitrary data record [9]-[11]. Growing rapidly more than other RFID markets, second generation active RFID—an enabling technology which integrates real time location systems (RTLS), machine to machine (M2M) via wireless or ubiquitous sensor networks (USN), IEEE 802.15.4/ZigBee, Ultra Wide Band (UWB), RuBee, Wi-Fi, culminating into Internet of Things (IoT) and more—was a market of $439 million in 2009 alone [12]-[14]. Due to massive scalability in RFID services, systems and networks, WSNs (or third generation RFIDs) as a subset have been driven by several factors: stronger market demand for wireless tracking, locating, monitoring and sensing people and things; reduction in cost and size of RFID tags; development of billions of widely deployed miniaturized sensors on everything (from livestock to food products and retail apparels with embedded smart cards); availability of open standard to emerging smartphone technologies; and government policies[15],[16]. Figure 1c illustrates the projection of the distribution of active RFID applications by market vertical from 2007 to 2017.

In estimation, over 141 suppliers and developers in 7 major geographic regions (North America, Asia-Pacific, Europe, South America, Russia and Australasia) have been identified in the field of WSNs in the capacities of IC vendors, start ups, carriers, handset OEMs and infrastructure providers (Figure 1d). Rapid growths are observed especially in China and Australasia with huge ID card and library schemes, and animals tagging. Clearly, industry giants such as Google, Microsoft and IBM indeed have pioneered the frontiers of wireless technologies segment with accelerated growths; however, matters of security, interference and interoperability at the application layer (user) have precipitated fragmentation at the consumer electronics (CE) segment. A case in point: In 2001, it was established that unauthorized interception, and access to wireless network transmissions was possible due to flaws in the 802.11 Wired Equivalent Privacy (WEP) security algorithm defined in the original standard. For that reason, IEEE 802.11i or Wi-Fi Protected Access 2 (WPA2) —an enhanced security solution—was ratified in 2004 by Wi-Fi Alliance, based on the Advanced Encryption Standard (AES) in contrast to the encryption protocol RC4 used in WEP. Wi-Fi Alliance is a trade association which promotes the technology and certifies interoperability of CE devices [17]-[19]. Further, in 2009, IEEE TGw published a set of standards to protect management and broadcast frames, which were previously sent unsecured. Thereafter, more security flaws were discovered in 2011 with Wi-Fi Protected Setup (WPS) feature that enables remote hackers to access WPS PIN, and by extension, passwords on 802.11i routers. Therefore, the next generation of wireless technologies must address lingering core MAC/PHY interoperability issues which exists, and still hinders peer-to-peer (P2P) Wi-Fi connections by consumers, limits audiovisual streaming, and reduces effective penetration of CE market.

Another noticeable evolution on the global scene, in wireless sensor technology, is the emerging IEEE 802.15.4f/g which defined the new wireless PHY layers, enhancement and MAC amendments of the Open System Interconnection (OSI) model of network operation to the existing IEEE 802.15.4-2006 standard. This was a follow-up on earlier PHY/MAC amendments 802.15.4c, d and e published between 2006 and 2011: For wireless PAN (WPAN) in China on 314-316, 430-434, and 779-787 MHz, to support a new frequency allocation in Japan that coexist with RFID tag systems on 950-956MHz, and to enhance industrial applications and permit compatibilities within the Low

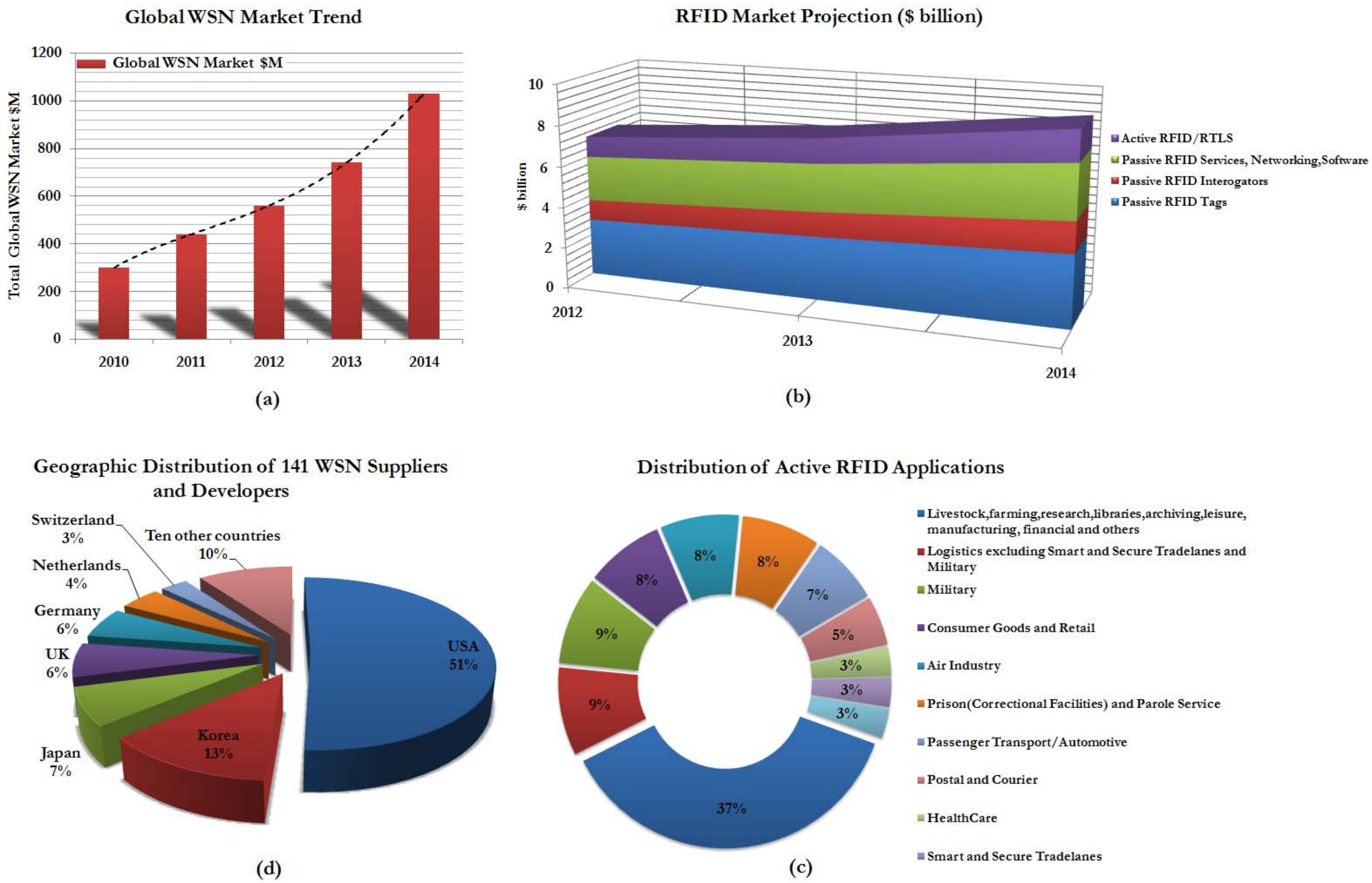

Fig.1. (a)Global trend of the WSN market between 2010 and 2014; (b)The projection of RFID Market from 2012 to 2014; (c) The distribution of active RFID applications from 2007 to 2017; and(d) The geographic distribution of 141 WSN suppliers and developers in 2010 (Sources: IDTechEx and ABI Research)

Rate WPANs respectively [20]. Released in 2012, IEEE 802.15.4g was an amendment that facilitated the implementation of very large scale (VLS) process control applications including smart utility networks (SUNs) for monitoring smart grid networks; while IEEE 802.15.4f supported active RFID systems with bi-directional and location-based applications. Notably, ZigBee, WirelessHART, ISA100.11a standards, and emerging technologies and competitive solutions such as Z-Wave, Low Energy Bluetooth, Low Power Wi-Fi, IPv6 over Low power Wireless Personal Area Networks (6LoWPANs), and standard Internet Protocols (IP) are further developments based on the IEEE 802.15.4 standard to achieve wireless embedded Internet [21],[22]. Figure 2a illustrates the LR-WPAN protocol stack features. In addition, IEEE 802.15.4 provided end-user oriented topologies which emphasized on low-cost, low-speed ubiquitous communication between devices with the fundamental lower network layers as the principal infrastructure. Currently, the standard on 2.4GHz band supports a throughput up to 250Kbps, and a physical range of 10m to approximately 100m. Moreover, the standard utilizes the Direct Sequence Spread Spectrum (DSSS) modulation technique at the PHY layer that fostered noise tolerance, reduction of interference, and minimized power consumption, using Carrier Sense Multiple Access-Collision (CSMA-CA) and Guarantee Time Slots (GTS) protocols for channel access. For good reason, the aforementioned multiplexing protocols allows multiple users or nodes access of the same channel at different times by two important topologies—the fundamental star and P2P —as basis of expansion into supplementary topologies in the upper network layer such as those observed in 'self-healing' and 'self-configuring' mesh networks or WSNs (Figure 2b).

Without question, the IEEE802.15.4 IC market trend is on an expected growth to over $1.1 billion in 2010, from $90 million in 2010; a CAGR of 72% over the next 5 years for ZigBee and other 802.15.4-based protocols. Worldwide, shipments of IEEE 802.15.4 WSN chipsets into the home are predicted to exceed 242 million/yr by 2015, up from 8.5 million in 2010 with a CAGR of 74% [23]. Further, the IEEE 802.15.4 IC market is expected to expand to over 850 million units per annum by 2016, with a CAGR of 60% from 2010—despite strong competitions from Low Energy Bluetooth, Low Power Wi-Fi, and Low Energy DECT [24]. Certainly, significant impetus was added to the market forces with mass deployment of profiles from over 350 ZigBee developers and suppliers to support IP-based solutions, the developments of ZigBee Smart Energy 2.0 (SEP2), and adoption of ZigBee/RF4CE specifications for 802.15.4 ICs (Figure 2c). Granted, growth is still attributed to Advanced Metering Infrastructure (AMI) as the major segment, however, the future of ZigBee anticipates adoption of emerging technologies for home area networks (HANs), to drive new application solutions. At the moment, IEEE 802.15.4/ZigBee has applications in other areas including: home automation and entertainment, and smart city concepts (traffic monitoring, smart parking, flood alert systems etc.); the ubiquity and price points that are achieved have enabled WSNs to extend broadly across markets. Figure 2d displays the global trend of WSN metering reading nodes unit value from 2011 to 2014. Consider the GS2000, the first emerging System on Chip (SoC) solution from two IEEE low power standard wireless technologies—Wi-Fi (802.11 b/g/n) and 802.15.4 PHY/MAC functionality—that featured a dual mode IPv4/IPv6 TCP/UDP networking stack with additional networking services, dual ARM Cortex-M3 processors and large memory size to support various IoT application profiles [25]. These attributes proffered the benefits of each technology: high data rates and availability of Wi-Fi, in addition to small channelization and mesh capabilities of ZigBee IP. Surely, then, the seamless integration of different platforms and standards into an extensive broad range of embedded system applications could deliver the next-generation WSN technologies. Equally important, though, the paradigm shifts of ultra low-power wireless technology toward Internet of Things (IoE) and the unique convergence of market growths have elicited innovations and spurned much development in another major sector—Location Based Services (LBS) and Indoor Positioning Systems (IPS), with and without the aid of the Global Navigation Satellite System (GNSS) infrastructure.

II. THE GNSS INFRASTRUCTURE AND THE NEXT-GENERATION WSN TECHNOLOGIES

Attractive features of the GNSS infrastructure—comprised of 4 global systems and at least 6 regional systems in Europe, Americas, and Asia—include the availability and interoperability of multiple signal spectra of a multi-constellation, suitable downstream services, and robust navigation capabilities to end users, aimed at fostering new GNSS applications. The intricacies of integration of GPS + Galileo + BeiDou + GLONASS with other emerging wireless technologies have not been without challenges and major milestones. Galileo, a joint initiative of the European Commission (EC), the European Space Agency (ESA), and the European Union EU, has successfully completed part of the In Orbit Validation (IOV) experimentation in 2013, with complementary system validation campaigns expected in 2014. Galileo is based on the IOV architecture made up of 30 satellites—a core constellation of 24 satellites with Full Operational Capability (FOC), six (6) active spares, a global network of ground infrastructure of base stations, and Control Centers for performance assessment, navigation mission monitoring and management [26]. Presently with four signal-broadcasting operational satellites in orbit, the average positioning accuracy of E1/E5a dual frequency (the band combination interoperable with GPS) is about 8m of horizontal position error (HPE) and 10m vertical position error (VPE) for Open Service users. Launched in pairs in October 21, 2011 and October 12, 2012, the IOV-3 carrier frequencies E1(1191.795MHz), E5 (1278.750MHz) and E6

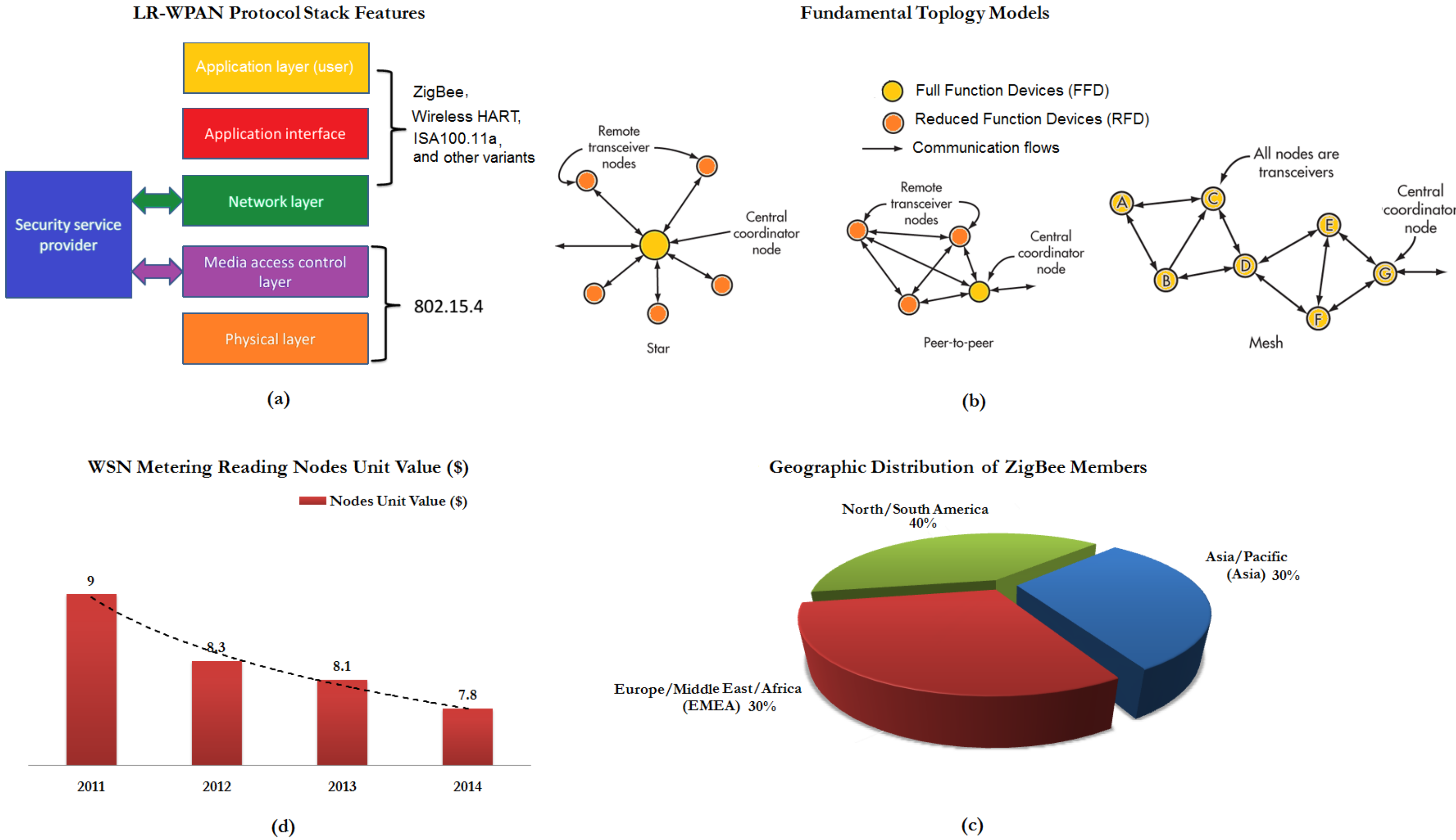

Fig.2. (a) The Low Rate WPAN protocol stack features; (b)The fundamental star ,P2P, and mesh topology models; (c) The geographic distribution of 350 ZigBee suppliers and developers in 2012; and(d) Global trend of WSN metering reading nodes unit value ($) from 2011 to 2014 (Source: Gartner)

(1575.420MHz) and associated modulation were activated in December 1, 2012 to initiate full in-orbit testing on E1/E5 and E1/E6 band combination. The pseudorandom measurements exhibited an acceptable low noise and multipath level of 10cm at mid- and high-elevation angles. Additionally, the analysis of the ranging signals E1 and E5 obtained from IOV-4 which were activated on December 12-13, 2012, is ongoing. The level of performance suggested the potential benefit of Galileo signals in advanced triple-frequency techniques, which is applicable in ambiguity resolution and ionosphere monitoring [27]. Though yet to be fully operational, Galileo's early service is to officially commence by the end of 2014. Table 2 shows expected early services in 2014 as further launches improve availability, positioning, timing accuracy and navigation. To that end, doors of opportunities are opened to commercial receiver technologies and chipset manufactures of all categories of end users, particularly with emphasis on development of cost-effective, flexible front-end, Galileo-compatible receivers, and the reception of multiple signals along with Galileo Open Service signal—GPS, GLONASS and BeiDou [28]. Contrary to the opinion of user community, guaranteed performance of Galileo vis à vis quality, efficiency, throughput, and safety, the service validation phase, market readiness, and optimization in multi-constellation environment or in difficult terrains such as urban canyons, are yet to be attained. Moreover, the need to evaluate the seamless transition from outdoor to indoor services to develop applications and market-oriented strategies targeted at assisted GNSS realization, cannot be overemphasized. At least 50% of over 60 GNSS receiver manufactures have incorporated European Geostationary Navigation Overlay Service (EGNOS) capabilities; while 30% have products supporting Galileo capabilities, and these supports have initiate pilot projects such as Intelligent Transport Directive, eCall for accident rescue services, digital tachography and GNSS-based road-pricing systems. Despite the appalling economic recession in Europe, and the €3 billion budget deficit (three times the original budget) used to launch 4 of 30 of the envisioned satellite constellation, an additional €6.3 billion has been approved by EU from 2014 to 2020 to secure the operational cost of Galileo and EGNOS, the completion of the initial constellation of 14 satellites (each with a 12-year working lifetime), and the procurement of second–generation orbiting set of 30 satellites.

Similarly, the Global Positioning System (GPS) constellation has experienced an additional L5 (1176.45MHz) to its 'legacy signals', the L1 (1575.42MHz) and L2 (1227.60MHz), from recently launched IIR and IIF satellite vehicles. Figure 3a shows the pseudorandom noise (PRN) 17 of a GPS satellite for position, navigation and time (PNT). The current active GPS constellation in 24+3 configuration (or 'Expandable 24') is a potpourri of 8 Block IIA satellites, 12 Block IIRs, 7 Block IIR-Ms and 4 Block IIFs with design life of 6-7.5, 7.5-10, and 10-12 years, respectively. Current efforts to sustain a constellation of healthy 24 satellites include—replenishment of unhealthy satellites by modernized GPS IIF and GPS III satellites, introduction of a fourth civil signal L1C for users, and development of the next-generation operational control system (OCX) to communicate with functional GPS III satellites[29]. In addition to the sustainability of the constellation, GPS civil users would have access to the L2C and L5 which broadcast the civil navigation message (CNAV). The signal L2C featured benefits of faster signal acquisition, improved reliability, and increased operation range; and L5 signal would enhance safety-of-life applications with increased bandwidth, broadcast power, and sophisticated signal design. Evidently, the GPS Standard Performance of Standard Positioning Services (SPS) has witnessed a decline in user range error (URE) from 1.6m in 2001, down to 0.8m in 2012 for signal-in-space (SIS), as a result of increasing developments and operational capabilities. More than that, these have driven GPS and GPS-enabled technologies to a crescendo of interoperability with Galileo, GLONASS, and BeiDou/Compass, to achieve a multi-constellation fix mode for higher reliability and accuracy, especially in urban canyons (where tall buildings reduces or reflect line-of-sight (LOS) signals) compared to GPS alone[30]. However, location is moving beyond GPS to ubiquitous IPS and LBS, owed to indoor and outdoor hybrid positioning technologies

TABLE 2. A SUMMARY OF GALILEO EARLY SERVICES

Galileo Early Services	
Services	Definitions
Open Service	Based on the E1, E5a and E5b signals; interoperability functionality of E1 and E5 with GPS for ranging.
Public Regulated Service (PRS)	Based on secure and stable E1 and E6 signals for EU Members, pilot projects, and PRS capabilities.
Search and Rescue (SAR)	Detection and localization of distress beacons.
Commercial Services	Demonstration of precise positioning, and authentication services with potential service providers.

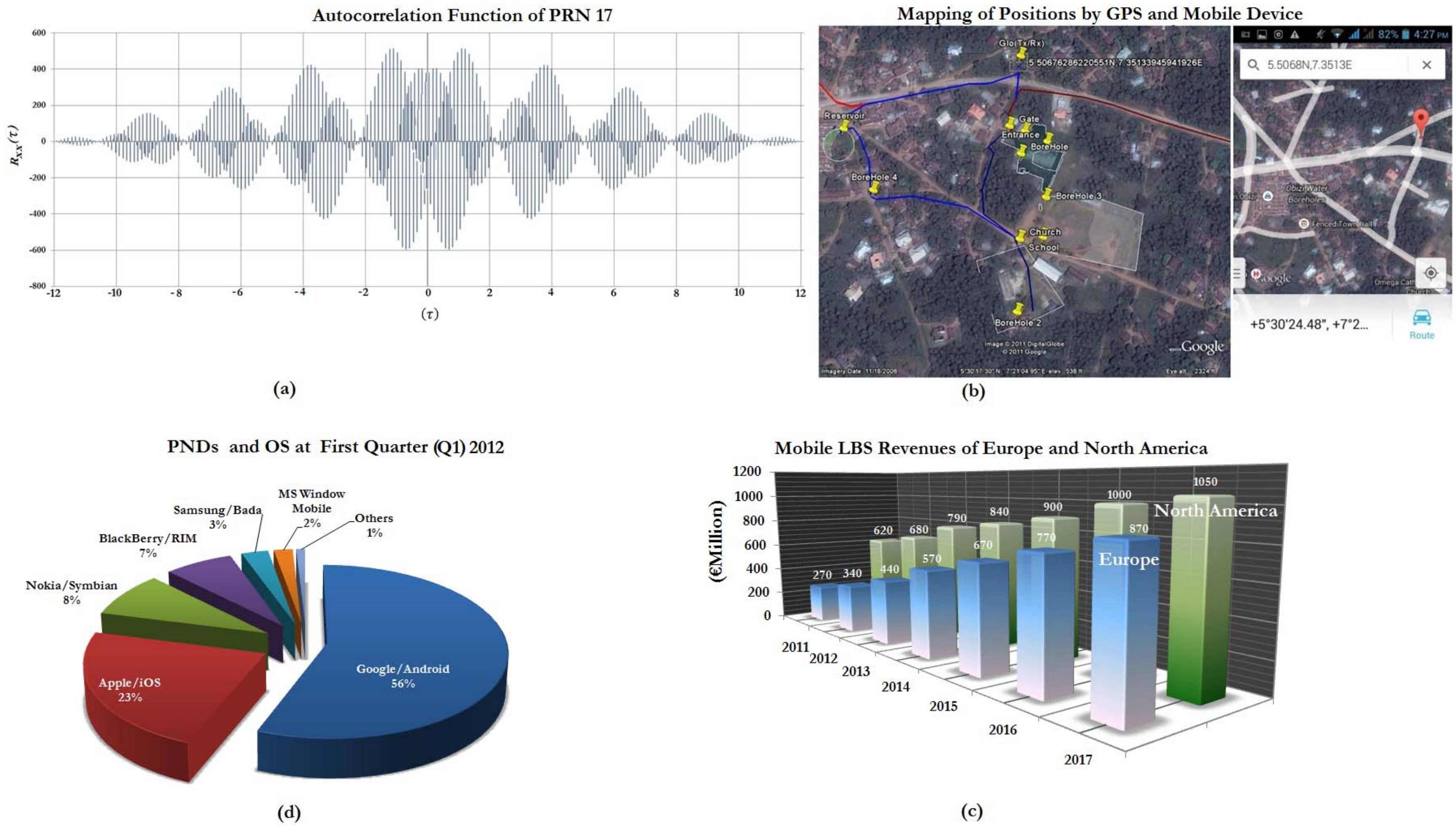

Fig.3. (a) The pseudorandom noise (PRN) 17spectrum for position location; (b) The comparative mapping of waypoints by GPS and mobile device; (c) The overview of personal navigation devices (PNDs) and operating systems (OS) at Q1 2012; and (d) The trends of mobile LBS revenues of Europe and North America between 2011 and 2017(Source: ABI Research).

and emerging sensor fusion currently exploited in mobile devices. A hybrid technology fuses signal measurement from cellular, Wi-Fi and Bluetooth network signal with data delivered by integrated inertial sensors in mobile devices such as accelerometers, gyroscopes, compasses, magnetometers, barometric height sensors and altimeters [31],[32]. For instance, in 2013, the chip BCM47531 that generates positioning data concurrently from a multi-constellation of about 88 satellites (GPS, GLONASS, QZSS, SBAS and BeiDou) was introduced into the location market to enhance smartphone positioning capabilities worldwide. The new GNSS SoC is on a widely adopted architecture that reduces time-to-first-fix or TTFF, utilizes a tri-band tuner which receives signals from all major navigation bands, which allow rapid location establishment, and ensure delivery of mapping data [33]. Figure 3b shows the comparative maps of the same waypoints by GPS and a typical mobile device. Unquestionably, the global market for indoor platforms is expected to rise at a CAGR of about 50% to €150 million by 2018. Additionally, as LBS become standard features in mobile devices, 1 billion smartphones is expected to have adopted location-base sensor fusion by 2016, providing huge potential to shopping malls, global transportation hubs, and existing satellite-based augmentation systems. The big impacts of the hybridization are evident in the volume shipment of smartphones, assisted GPS (A-GPS) and A-GNSS chipsets (A-GLONASS is at the horizon), and developments in Wi-Fi connectivity of embedded and near field communication (NFC) systems (Figure 3c and d). Specifically, retail indoor location market is expected to attain $5 billion in 2018, and in support of these technologies, smartphone retail application would break 1 billion downloads, while indoor maps record would break 1 million buildings over the forecast period. Overall, annual revenues of A-GPS servers, passive location platforms, and middleware deployed by mobile operators are on trajectory of €14.2 million p.a., from €190 million in 2012 to reach €275 million in 2018, worldwide. Even so, growing concerns of GPS community to continuous vulnerability of GPS signals to interferences, jamming potentials and spoofing attacks remain unabated (the LightSquared L-Band scenario) [34], neither have the emerging hybrid solutions been augmented unto a common platform or standard; the evolution and implementation of the hybrid positioning technology solutions are still very fragmented and proprietary. True, mobile application management and security is presently in a metamorphosis; nonetheless, waves of prospects of WSN applications are projecting the GNSS infrastructural base toward innovative WSNs. In 2010, the global market experienced the start of the next-generation Wi-Fi modules, the WSN802G series: A certified low-power 2.4GHz IEEE 802.11g radio transceiver modules that connect existing 802.11b/g WLAN infrastructures to WSN solutions [35]. The 11Mbps active module featured the GS1011 SoC which supports master/slave SPI port functionality (for interface of sensors and low-cost microprocessors), WPA2-Enterprise security (IEEE 802.11i), an ad hoc mode which provides point-to-point capabilities, and compatible pin formats with some WirelessHART and ZigBee/802.15.4 series modules.

In the mean time, BeiDou/Compass and GLONASS by China and Russia respectively are opening up services for global availability at an acceptable reliability and accuracy levels to users. The BeiDou Navigation Satellite System (BDS) is a constellation of five (5) geostationary orbit (GEO) satellites, 27 medium Earth orbit (MEO) satellites with mean period of 12.89 hours, and five inclined geosynchronous orbit (IGSO) satellites inclined at angles 55°, intended for China, Asia-Pacific and global users. By 2020, approximately 40 satellites are expected to have been launched into orbits with improved and enhanced performance over present configuration: Carrier-phase differential accuracy of about 3cm, timing accuracy of 50ns, and single-frequency horizontal, vertical and 3D positioning accuracy of 10, 10, and 14m, respectively [36]. For a constellation with an inception since 1980, the role of BDS to satellite navigation and LBS in China is estimated to be $13.2 billion in 2012, an equivalent of 8% of the global sector. Moreover, at the end of year 2012, BDS civil user terminals accrued to 230,000 units, and BDS-related industrial activities was equivalent to about $652 million. On the other hand, extensive efforts are directed toward GLONASS expansion and sustainment, by development of new generation of GLONASS-M satellites planned for launch between 2014 and 2015. In addition to 24 healthy satellites, the new navigation satellite (GLONASS-M-55) would provide navigation services for user with frequency-division multiple access (FDMA) on L1 and L2 signals, and code-division multiple-access (CDMA) on L1(1602MHz), L2(1246MHz) and L3(1202MHz) signals. Though BeiDou is making impulsions toward multi-constellation, however, the earlier non-availability of the interface control document (ICD) has hampered rapid major hardware developments of receivers. Integration of GLONASS (1602MHz on FDMA) and BeiDou (1561MHz) to the RF front is expected to cost extra silicon in digital hardware, by extension power consumption and increased jamming vulnerability. Early application of developments is underscored by the new quad-constellation Teseo-3 receiver which features an RF front-end integrated with digital silicon and flash memory, enabling simultaneous reception of Galileo, GPS, GLONASS and BeiDou signals. By 2020, four (4) global constellations would be on the same band, over 100 satellites would be made available, and with a clear sky, about 30-40 satellites simultaneously could be tracked using multi-frequency receivers. Beyond that, GLONASS is to have L1OC signal operational, while GPS/Galileo and BeiDou are projected to utilize B3 signals in CDMA on 1575MHz band [37]. Succinctly summarized, performance benefits would include―Increased urban canyon visibility, improved accuracy, and flexibility of switching between multi-frequencies. How these forward-thinking momentums would revolutionize the biggest trend in LBS though remain yet to be seen, nevertheless, these location technologies would induce in outdoor and indoor mapping a major concept—ubiquitous positioning.

III. UBIQUITOUS POSITIONING AND EMERGING REAL-TIME DISTRIBUTED DATA NETWORKS

Locations everywhere and anytime are major concepts to ubiquitous position, and GPS alone would not suffice to support the next-generation of location market technologies. The key to ubiquitous location across a variety of portable devices—mobile phones, smartphones, tablets, and laptops—is the proliferation of Wi-Fi distributed data networks and low-cost free location engines. The hybrid approach of emerging location technologies: Wi-Fi, MEMs, barcodes, NFC and RFID, Bluetooth, and closed-circuit television (CCTV) have sustained vital services such as local search, location-based advertising, and geotagging, social networking, with augmented data networks to increasingly improve indoor location. Notably, A-GPS-enabled and A-GNSS-enabled mobiles have moved into the Long-Term Evolution (LTE) or 4G wireless transmission based on LTE Positioning Protocol (LPP) and Secure User Plane Location (SUPL) 2.0 and 3.0 standards. Further, the A-GNSS technology involves high-sensitivity signal processing to acquire weak satellite signal, and provide assistance data such as approximate position (in 2-D or 3-D profiles), time and other related satellite-orbit parameters. The *de facto* standard—3rd Generation Partnership (3GPP) Radio Resource Location Service Protocol (RRLP) Technical Specification (TS) 44.031 positioning protocol—has been updated with releases 7,8 and more recently LTE 9 to improve the native capabilities of TTFF, accommodate GNSS assistance data of modernized GPS, GLONASS, Galileo, and a selection of SBASs [38]. Furthermore, the protocol defines positioning procedures and data delivery to global systems for mobile communications (GSM), universal telecommunications system radio access (UTRA), CDMA networks, and evolutions of WiMAX (802.16m) equipments. Admittedly, the backbone infrastructure of ubiquitous positioning would remain the global GNSS base stations: Typical positioning performances statistics from a 20-day ensemble time series analysis of a base station, located at longitude 4.5393°E and latitude 7.5319°N, recorded a HPE mean of 3.8695m, σ of 0.6896m, and a 95% horizontal position accuracy of 6.795m, while VPE mean of 6.5340m, with σ of 1.2088m, and a 95% error bound of about 12m characterized the vertical position accuracy. Moreover, with a clear sky, the representative satellite geometry data—the horizontal, vertical and position dilution of precision (HDOP, VDOP and PDOP) averaged 1.1271, 1.8686 and 2.2093 respectively with corresponding σ of 0.2262, 0.3664 and 0.3833. Based upon the base station evaluations as synchronized reference locations, the location server in a network assists mobile user equipment (UE) to decode ephemerides data, request and perform continuous navigation seamlessly from outdoor to indoor scenarios. Interestingly, though, indoor positioning accuracy achievable is still above 10m. For that reason, the Request/Provide Assistance Data mechanism in most data network is in development stage, to accommodate environments where satellite visibility is impaired.

Research and Development (R&D) in emerging real-time distributed networks includes cloud-based radio access network (C-RAN), an innovative creation of the collaboration between Intel and China mobile. In contrast to the traditional RAN, C-RAN is the foundation to modern cellular networks in which proprietary base station hardware are substituted with standard Intel-based servers operating on software-defined radio application (apps), with the advantages of cost reduction for wireless service providers and improved services to users. Another area of research is referred to as the video aware wireless network (VAWN), a joint academic research program sponsored by Intel, Cisco and Verizon. The VAWN is aimed to boost the streaming video capability of wireless networks by optimizing the network performance between service providers and users [39]. This is expected to drive markets for indoor location platforms, supporting technologies, and related commercial services of about 150,000 shopping malls and major transportation hubs worldwide to a CAGR of about 50% to reach €150 million by 2018. In addition, Intel Smart Connect technology have designed APIs to manage intelligently communications of cloud connected devices—to ensure efficient delivery of incoming network traffic and low-power consumption using standby mode options, without impacts to the performance of the system. Alongside, Intel Labs has developed a new client-based authentication technology in an effort to protect sensitive information without the use of passwords. The authentication technology substantiates connections to cloud devices using biometric sensors, and provides the virtual experience of connecting users directly to bank accounts, stock portfolios, social network pages, or any kind of cloud-based secure services. Moreover, the authentication technology is imbued with presence-monitoring capabilities that locks and unlocks the platform with new biometric scan, to secure connections when the device is down.

IV. PATTERN RECOGNITION IN ACQUIRED DATA: THE FRACTAL AND CHAOS PERSPECTIVES

Indeed, the advents of cost-effective WSNs have stimulated GPS/GNSS tracking, pioneered rapid data distribution, promulgated sensor fusion and resolved challenges of sensor deployment to an extent. Yet, the evolution of detection and mitigation techniques of measurement, estimation and prediction of optimal signal descriptors that defined parts of the positioning problems, are far from achievable standard and performance capacity, especially as terrestrial signals become unreliable or noisy. Additionally, the chaotic dynamics of WSNs have questioned the programmability techniques, computational capability of existing processing systems found in position and location management systems. Insights into the acquired data in

WSNs suggest that fractal geometry of sensor locations dictates to a large degree the integrity of an array. For instance, the statistical self-similarity in PRNs spectra—the effect of symmetries across scale, with each small structure replicating the structure of the whole, revealed convergences of Gaussian density distributions. Such mathematical fractals are observed in logarithmic spirals, Sierpinski gaskets, quadratic Koch curves, and Merger sponge to mention a few [40]. Added to that, the 50% circular error probable (CEP): HPE of 3.2685m and VPE of 5.7717m of a typical GPS base station characterized the topology dimensions of the WSN array—placement of various nodes—on scales of magnification. Significantly, similar cycles of ensemble averages of observable position data further underscored the use of reference stations as baselines of deep indoor positioning. Largely, the trajectories of the chaotic dynamics of the data transmission and fault tolerance could be analyzed with chaotic attractors to unfold the butterfly effect of variations—the universality of chaotic systems [41].

V. GLOBAL WSN DEVELOPMENTS: THE FUTURE OUTLOOK

Clearly, the door of successful implementations of WSN developments hinges on availability, sophistication, and costs of standard ICs. The emergence of wireless home automation has provided forums for manufactures and application developers to deliberate on standardized, open protocols of connected home devices and sensors. The unique convergence of application specific integrated micro-instruments (ASIMs)— microelectronics, integration of micro-electromechanical systems (MEMs), miniaturization, and signal conditioning—have developed into ultra low-power 6LoWPAN WSNs managed on harvested energy—ambient energy captured and converted into usable electricity for small autonomous devices. Currently, IoT is a concept pushing the boundaries of WSNs across information systems to property management, transportation, home environment, and energy production. Round the corner, hypes about transitions into Internet of Everything (IoE) predict billions of IoE devices over the next 10 years. Nevertheless, these major milestones are but extensions of hybrid location solutions of GPS/GNSS applications.

Investment in parallel developments in GPS/GNSS applications in 2010 was estimated to be €130 billion in global GNSS market share. By 2020, expected growth in contribution to GNSS applications R&D is estimated to be €240 billion. Beyond doubt, the next few years would be crucial to the growth phase of downstream sector of GNSS application and its relevance to WSN markets. Enthusiastically, in 2018, 9.7 million Carrier Wi-Fi access point shipments are anticipated, with Asia-Pacific accounting for 70% of the total [42]. Additionally, Wi-Fi-enabled receivers and transceivers would access cellular and high-data rate networks and seamlessly provide navigation benefits. In the meantime, the timing industries with advancement of silicon MEMs solutions would improve performances of oscillators and limitations of quartz—critical to GPS/GNSS applications. State of the art RF front-ends would constantly evolve the market to resolve induced impedances, system noises, and jamming effects of high energy sources. Evidently, the voyage of WSN would transcend the hazy horizon of fragmentation to reveal ubiquity of integrated next-generation wireless technologies—toward achievements of efficient data distribution.

REFERENCES

[1] "IEEE Standard for Information technology—Telecommunication and information exchange between systems, Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification," IEEE Std. 802.11-2012 Standard document, Retrieved 01/02/2014 World Wide Web, http://standards.ieee.org/getieee802/download/802.11-2012.pdf.

[2] "IEEE 802.11™ wireless local area networks: The Working Group for WLAN Standards", Retrieved 01/02/2014 World Wide Web, http://www.ieee802.org/11/

[3] Xiang, C. and Z. Guo-hua; "Research on Design Scheme of WLAN communication Adapter Based on 802.11 Protocols," *Physics Procedia*, vol. 25, pp. 899-904, 2012.

[4] "IEEE 802.15 WPAN™ Task Group 4 (TG4): WPAN Home Page", Retrieved 02/02/2014 World Wide Web, http://www.ieee802.org/15/pub/TG4.html.

[5] IEEE Standard for Information technology—Telecommunication and information exchange between systems, Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, Amendment 1" IEEE Std. 802.11-2012 Standard document, Retrieved 01/02/2014 World Wide Web, http://standards.ieee.org/getieee802/download/802.11ad-2012.pdf.

[6] IEEE Standard for Information technology—Telecommunication and information exchange between systems, Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, Amendment 2" IEEE Std. 802.11-2012 Standard document, Retrieved 01/02/2014 World Wide Web, http://standards.ieee.org/getieee802/download/802.11aa-2012.pdf.

[7] "IEEE Standard for Information technology—Telecommunication and information exchange between systems, Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, Amendment 3" IEEE Std. 802.11-2012 Standard document, Retrieved 02/02/2014 World Wide Web, http://standards.ieee.org/getieee802/download/802.11ae-2012.pdf.

[8] "Wireless Health Market to reach $38bilion by 2016", Retrieved 02/02/2014 World Wide Web, http://www.sensorsmag.com/networking-communications/wireless/news/wireless-health-market-reach-38-billion-2016-9815.

[9] "ABI Research: RFID—Market Data Q3 2013 MD-RFMT-156", Retrieved 02/02/2014 World Wide Web, https://www.abiresearch.com/research/ product /1014173-rfid/

[10] Das, R., "IDTechEx: Global RFID market will reach $7.88 billion in 2013", Retrieved 24/12/2013 World Wide Web, http://www.idtechex.com/research/articles/global-rfid-market-will-reach-7-88-billion-in-2013-00005914.asp.

[11] Tsai, M-C., K-H. Lai, and W-C. Hsu;"A study of the institutional forces influencing the adoption intention of RFID by suppliers," *Information & Management*, vol. 50, pp. 59-65, 2013.

[12] Carlaw, S. *et al.*; "M2M and Internet of Things," *ABI Research, The Connected World of Tomorrow—Predictions for 2014 and 2015*, pp. 28, 29, 2013.

[13] "FTC Seeks Input on Privacy and Security Implications of the Internet of Things", Retrieved 02/02/2014 World Wide Web, http://www.ftc.gov/news-events/press-releases/2013/04/ftc-seeks-input-privacy-and-security-implications-internet-things.

[14] Ferrari, P. *et al.*; "Improving simulation of wireless networked control systems based on WirelessHART," Computer Standards & Interfaces, vol. 35, pp. 605-615, 2013.

[15] Wamba, S. F., A. Anand, and L. Carter; "RFID Applications, Issues, Methods and Theory: A Review of the AIS Basket of TOP journals," *Procedia Technology*, vol. 9, pp. 421-430, 2013.

[16] Lee, C.K.H. *et al.*; "A RFID Resource Allocation System for garment manufacturing," *Expert Systems with Applications*, vol.40, pp. 784-799, 2013.

[17] Gold, S.; "Cracking wireless networks," *Network Security*, vol. 2011, pp.14-18, 2011.

[18] Haines, B.; "Chapter 1: 802.11Wireless—Infrastructure attacks," in *Seven Deadliest Wireless Technologies Attacks*, pp.1-24, 2010.

[19] Granado-Criado, J. M. *et al*.; "A new methodology to implement AES algorithm using partial and dynamic reconfiguration," *Integration, the VLSI Journal*, vol. 43, pp. 72-80, 2010.

[20] "IEEE Standard for Information technology—Telecommunication and information exchange between systems, Local and metropolitan area networks—Specific requirements, Part 15.4: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification for Low-Rate Wireless Personal Area Networks (WPANs)," IEEE Std. 802.11-2012 Standard document, Retrieved 03/02/2014 World Wide Web, http://standards.ieee.org/getieee802/ download/802.15.4d-2009.pdf.

[21] Wang, X. and S. Zhong; "A hierarchical scheme on achieving all-IP communication between WSN and IPv6 networks," *AEU - International Journal of Electronics and Communications*, vol. 67, pp. 414-425, 2013.

[22] Piro, G. et al.; "Information centric services in Smart Cities," Journal of Systems and Software, vol.88, pp.169-188, 2014.

[23] "ABI Research Evaluates IEEE 802.15.4 IC Market", Retrieved 04/02/2014 World Wide Web, http://www.sensorsmag.com/networking-communications/wireless-sensor/news/abi-research-evaluates-ieee-802154-ic-market-9300.

[24] "IEEE 802.15.4 IC Market Expected to Expand", Retrieved 04/02/2014 World Wide Web, http:// www.sensorsmag.com/networking-communications/wireless/news/ieee-802154-ic-market-expected-expand-9912.

[25] "GainSpan Unveils Wi-Fi and ZigBee IP Single Chip", Retrieved 04/02/2014 World Wide Web, www.sensorsmag.com/networking-communications/wireless/news/gainspan-unveils-wi-fi-and-zigbee-ip-single-chip-11075.

[26] Olorunniwo, O. and M. A. Olorunniwo, "GPS, GALILEO, and Nanotechnology: A Cost-Effective Satellite Technology?," *in Papers presented at PICMET'10* [CD-ROM], eds.: D.F. Kocaoglu, T.R. Anderson, K. Niwa, Portland, OR: PICMET, July 2010.

[27] Olorunniwo, O. and B. O. Salu, "Evolving Space Technologies, Climate Change, and Energy Efficiency: A Sustainable Scenario?," *PICMET'11 Conference,* in press.

[28] Lisi, M.; "Galileo "Early Services" Promoting New Applications and Products," *Proceedings of the 26th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2013)*, pp. 1731-1747, 2013.

[29] Willard, M. and S. Michael; "Design of the GPS III Space Vehicle," *Proceedings of the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2011)*, pp. 3067-3075, 2011.

[30] Wang, L., P. D. Groves and M. K. Ziebart; "GNSS Shadow Matching: Improving Urban Positioning Accuracy Using a 3D City Model with Optimized Visibility Scoring Scheme," *NAVIGATION, Journal of The Institute of Navigation*, vol. 60, pp. 195-207, 2013.

[31] Jing, H, *et al.*; "Wi-Fi Indoor Localisation Based on Collaborative Ranging Between Mobile Users," *Proceedings of the 26th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2013)*, pp. 1317-1324, 2013.

[32] van Diggelen, F.; "Deep Indoor Navigation – The End of the Beginning," *Proceedings of the 23rd International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2010)*, pp. 1704-1723,2010.

[33] "Broadcom Announces New GNSS Location Chip", Retrieved 04/02/2014 World Wide Web, http://www.sensorsmag.com/sensors/news/broadcom-announces-new-gnss-location-chip-support-chinese-12338.

[34] Olorunniwo, O. and M. A. Olorunniwo, "Technology Management: GNSS and the Interference Saga," *PICMET'13 Conference Bulletin,* in press.

[35] "RFM Announces Next-Gen Wi-Fi Modules", Retrieved 04/02/2014 World Wide Web, http://www. sensorsmag.com/networking-communications/wireless/news/rfm-announces-next-gen-wi-fi-modules-7214.

[36] Yang, Y. *et al.*;"Basic Performance of BeiDou Regional System," *Proceedings of the ION 2013 Pacific PNT Meeting*, pp. 221-246, 2013.

[37] Mattos, P.G. and F. Pisoni;"Quad Constellation Receiver - GPS, GLONASS, Galileo, BeiDou," *Proceedings of the 26th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2013)*, pp. 176-181, 2013.

[38] Anderson, P., E. Anyaegbu and R. Catmur; "The Future of Multi-Constellation GNSS Test Standards for Cellular Location," *Proceedings of the 25th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2012)*, pp. 141-150, 2012.

[39] "Intel's Vision of a Wireless Future", Retrieved 05/02/2014 World Wide Web, http://www.sensorsmag. com/ networking-communications/wireless/news/intel-s-vision-wireless-future-10364.

[40] Singh, S. L., S. N. Mishra and W. Sinkala; "A new iterative approach to fractal models," *Communications in Nonlinear Science and Numerical Solutions*, vol.17, pp.521-529, 2012.