Another Branches and Challenges of Sensor Networks Evolution

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Abstract— Wireless sensor networks have been identified as one of the most important technologies for the 21st century [2]. They consist of nodes with wireless communication, sensing, and computation capabilities [3]. Earlier paper [2] predicted that the size of sensor will smaller and smaller like a dust and will not use IP protocol due to inefficiency reason. But today, wireless sensor evolution takes different path. The sensor size is become smaller as predicted but it is become dependent devices, the smaller sensor become part of other comprehensive devices like smart phone or special purpose device like spy planes or missiles. This paper present the new direction of wireless sensor evolution, which wireless sensor leave the communication part to special communication devices and use public communication based on IP protocol. Sensor based application starting to appear in smart phone along with spectacular smart phone user growth [14] which often includes camera, accelerometer, GPS, compass, touch sensor, gyroscope, and optical sensor, beside microphone and radio as a basic sensor.

Keywords— Sensor, Smart phone, Sensor based application, Sensor evolution, IP based network, Sensor Trend

I. INTRODUCTION

Sensor network development can trace back to early history since cold war, which sensor size quite big compare today sensor technology. The development of sensor networks requires technologies from three different research areas: sensing, communication, and computing (including algorithms, software, and hardware). Continues advancements in each of these areas have been driving research in sensor networks. Examples of early sensor networks include the radar networks used in air traffic control. The national power grid, with its many sensors, can be viewed as one large sensor network. These systems were developed with specialized computers and communication capabilities, and before the term "sensor networks" came into vogue [2].

On the previous paper, mentioned that smart wireless sensors can be deployed in the air, under water, on bodies, in vehicles, on the ground, and inside buildings. A system of networked sensors can detect and track threats (e.g., winged and wheeled vehicles, personnel, chemical and biological agents) and be used for weapon targeting and area denial. Each sensor node will have embedded processing capability, and will potentially have multiple onboard sensors, operating in the acoustic, seismic, infrared (IR), and magnetic modes, as well as imagers and micro-radars. Also onboard will be storage, wireless links to neighbouring nodes, and location and positioning knowledge through the global positioning system [2]. Unfortunately trend that sensor will be placed in smart phone and home appliance never mentioned.

Sensor network is key technology in 21st century but many papers [2][3][5][6][7][8] focus on wireless sensor as independent devices only, they capable to communicate each other. IP Protocol was considered as not viable solution due to inefficiency [2][3]. Those papers never mention how often each sensor communicates to each other and how big data need to be transferred. However IP based communication become ubiquitous today. IP based devices can easily become network aggregator and offer efficient communication for multiple sensors in single devices and also for large data transfer like from imaging sensor and voice sensor.

In the previous definition, sensor networks is considered to deploy own communication system. It was clearly mention in paper [2] and paper [3]. Wireless sensor networks consist of nodes with wireless communication, sensing, and computation capabilities. They can potentially deploy large numbers of sensors. The sensors themselves can measure the environment over time and generate data, from which we seek to extract relevant information. The sensor nodes communicate with their neighbours wirelessly, and cooperate with each other in processing the data [3].

From the viewpoint of communications, sensor networks are wireless add hoc networks formed by nodes which communicate with neighbouring nodes over a wireless channel. Nodes in the network cooperate in sending data concerning each other. An important desirable global property of such a wireless ad hoc network is that it is auto connected. This is particularly important in sensor networks, where achieving a common application objective may require communication among all the nodes. An important example is when some information concerning all the sensor nodes needs to be collected by a designated fusion node [3].

Contrary to the previous prediction, sensor network now become more dependent devices. They attached to the special network devices or to more comprehensive devices –like smart phone- to communicate with server or other sensor. They most

likely use public communication infrastructure like 2G/3G/4G or even Wifi. Popular sensor, such as: accelerometer, GPS, compass, touch sensor, gyroscope, optical sensor, and camera with better than 5-megapixel resolution have been attaching to smart phone devices. These are used in addition to the compulsory sensors, such as the microphone, radio and others that provide basic functions [1]. Another type of sensor also emerges, like network sensor and software based network sensor.

This paper will present another branches and challenges of sensor networks evolution, starting with Introduction in part I then followed by Old Prediction in part II. Enabler Devices in Current Situation will be discussed in part III, followed by New Branches of Evolution in part IV. Challenges that faced in new evolution path will be presented in part V, followed by Conclusion in part VI.

II. The Old Prediction

In the previous paper [2][3], evolution for sensor network in 2013 onward was predicted to have following general characteristics:

A. Technology Trend

Looking into future (2013) onward, sensors were expected to more capable and versatile, having following characteristics:

- Size of sensor : Dust Particle
- Weight : Negligible
- Topology : Peer to peer
- Deployment : Embedded, "springkled" left behind

Those micro sensors are disposable and capable to communicate each other, sharing their data. Due to enhancement in sensor devices capability, sensor can deploy in embedded system as sensor network.

B. Networks

Sensors will be implemented mostly using wireless communication feature as independent wireless network sensor using special protocol. Heterogeneous implementation was considered as better approach in term of energy efficiency [5][6]. IP protocol, either IPv4 or IPv6 weren't considered as viable solution due to header inefficiency [2][3] despite of its ubiquity present. Unfortunately, size of data that send by sensor and how often the sensors send the data never mention clearly on related paper.

C. Applications

Originally motivated by military application and then spread over to many other potential applications, such as infrastructure security, industrial sensing, environment and habitat monitoring, and traffic control [2]. It was predicted that application is peer to peer among sensors in sensor network. Personal application sensor and smart phone apps based sensor have not mention yet.

D. Topology

Many network topologies compared as viable solution [7] but all solution offered sensors to be implemented as independent devices. They can communicate each other directly without device special communication purpose like GSM modem.

E. Challenges

Sensor network in general pose considerable technical problems in data processing, communication, and sensor management but at the same time have hard challenge such as:

- Ad Hoc Network Discovery
- Network Control Routing
- Collaborative Signal Information Processing
- Tasking and Querying
- Security

However standard and interoperability have not predicted as another hard problem.

III. Enabler Devices for Evolution Branches

The development of microprocessor technology allows the implementation of sensors in the devices used day to day by more people. Here are the things – but not limited to- that become enablers of new branches of the sensor network evolution.

A. Mobile User

Number of registered mobile phone users reached 6.8 billions people worldwide and penetration reach 96.2%. Moreover, mobile broadband subscriber growth reach 40%, and now there are about 2 billions mobile broadband subscribers worldwide as depicted in table 1. Mobile broadband become a perfect enabler for further development of sensor network. Bandwidth provided by mobile broadband is expected to suffice for a sensor apps including data intensive sensor like imaging. Beside that, individual user experience also continue to grow, they use their handhelds not only to communicate, but also for other things including sensors.

TABLE I
KEY GLOBAL TELECOM INDICATORS FOR THE WORLD TELECOMMUNICATION SERVICE SECTOR IN 2012

Description	Global	Africa	Arab State	Asia & Pacific	CIS	Europe	The Americas
Mobile cellular subscriptions (Millions)	6835	545	396	3547	476	790	1048
Per 100 people	96.2%	63.5%	105.1%	89.7%	169.8%	126.5%	109.4%
Fixed telephone lines (millions)	1,171	12	35	515	72	243	272
Per 100 people	16.5	1.4%	9.3%	12.9%	25.7%	39.0%	28.4%
Active mobile broadband subscriptions (millions)	2,096	93	71	895	129	422	460
Per 100 people	29.5%	10.9%	18.9%	22.4%	46.0%	67.5%	48.0%
Mobile broadband growth	40%	82%	55%	22%	27%	33%	28%
Fixed broadband subscriptions (Millions)	696	3	12	303	38	168	164
per 100 people	9.8%	0.3%	3.3%	7.6%	13.5%	27.0%	17.1%
Source: © International Telecommunication Union (February 2013)					via: © mobiThinking		

B. Smartphone

Smart phones have tremendous computing capabilities. They're like a mobile computers, sensors easily can be integrated as part of a smart phone features. As shown in Table II below, the growth of Smartphone shipments also increased significantly. From the year 2011 to the year 2012 the growth reached 44%.

TABLE II
TOP FIVE SMARTPHONE VENDORS, SHIPMENTS, AND MARKET SHARE IN 2012 (MILLIONS OF UNITS), ACCORDING TO IDC

Vendor	2012		2011	
	sales (Millions)	market share	sales (Millions)	market share
Samsung	215.8	30.3%	94.2	19.0%
Apple	135.9	19.1%	93.1	18.8%
Nokia	35.1	4.9%	77.3	15.6%
HTC	32.6	4.6%	43.6	8.8%
BlackBerry (RIM)	32.5	4.6%	51.1	10.3%
Others	260.7	36.5%	135.3	27.5%
Total	712.6	100.0%	494.6	100.0%
Source: © IDC (Jan 2013)				

C. Personal Computer and Laptop

Performances of PCs are more powerful with an affordable price now adopted by more people. Worldwide shipments of PC or laptop also increase from year to year as shown in Figure 1 below. PC or laptop that installed in homes could easily become gateway of the home sensor or even as a host of the sensor itself, in particular sensors that associated with energy use, personal ID and web traffic.

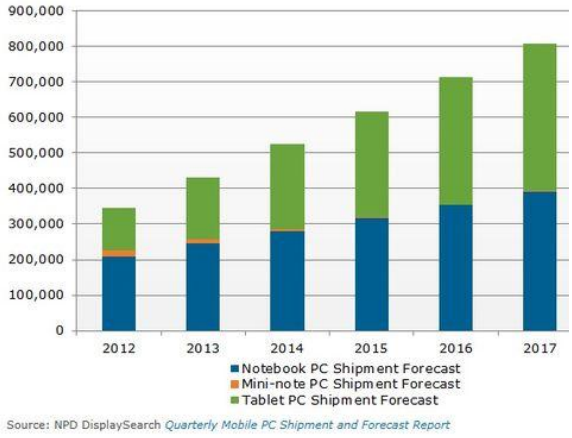

Figure 1: PC Shipment world wide

D. Smart Home appliance

Smart home appliance [15] implement micro sensor and controlled remotely by smart phone via public cellular network as shown in figure 2. Equipment which belongs to the category of smart home appliances are:

- Smart washing machine
- Smart TV
- Smart lamp controller
- Smart home security appliance
- Smart fridges
- Smart stove
- etc

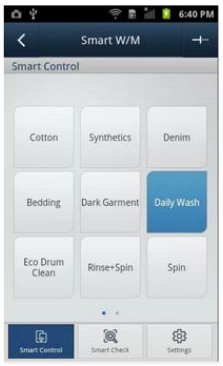

Figure 2: Smart home appliance controlled by smart phones, source: www.google.com

E. Smart Car and Unman Military Tools

Number of vehicles in smart car category is also immerge starting with high class cars. This is in line with the need to improve the driving comfort, especially in the regular path. Smart car is equipped with a microcomputer easily become a host for the sensors.

Given the high danger on the battlefield, modern warfare will use unman tool like unman aircraft [16] as depicted in Figure 3.

Figure 3: Unman aircraft, source: http://www.fas.org

The use of unman military tools also become an enabler in wider use of sensors.

F. Galactic Exploration

Exploration of outer space as Saturn Explorer Cassini –depicted in figure 5- requires reliable and accurate sensors. Data from space will be sent to the ground station using a communication device mounted on the vehicle airspace.

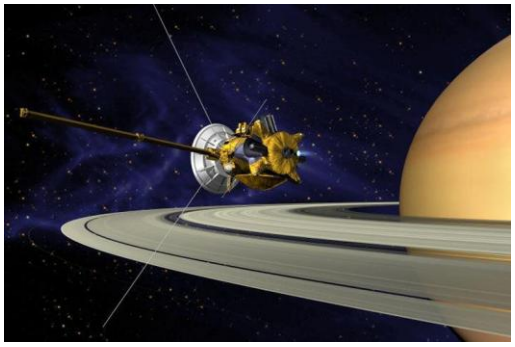

Figure 4: Saturn explores Cassini, source: www.redorbit.com

IV. New Branch of Evolution

Although computer and mobile phone already ubiquitous in 2003, but hand phone and computer capability have not considered as serious host for sensor at that time. But recently, growing capability of computer and smart phone reach certain level that make implementation of sensor more viable. Sensor more likely become complement to other more comprehensive devices like Smartphone, PC, Laptop, Home appliance, unman military tool, and even galactic exploration devices.

Leveraging the sensor implementation enablers mentioned in Part III is opens a new branch for the evolution of the sensor network which has characteristics such as:

- Dependent devices
- Communicate using public network
- IP based protocol
- Server based topology
- Add on application
- Special purposes sensor

A. Dependent Devices

Sensor is predicted only to become part of more comprehensive devices mention in part III. Although the ability of micro sensor could be improved to have capability to communicate directly each other, to directly compute data results, and to store the result in local memory, but sensor tend to use special purpose feature of enabler devices instead of its own. Using device enabler –such as Smartphone resources is efficient solution for whole system.

B. Public Network

Because enabler device communicates with other devices using public networks such as 2G/3G/4G then sensor installed in the device enabler will also use the public network to transmit sensing results.

C. IP based protocol

IP protocol both IPv4 and IPv6 are the options that will be taken since the protocol is widely used in communications in the enabler devices. Additionally IP is a protocol that adopted by many developers, pushing application based on sensor will be IP based too.

D. Server Based Topology

Although the sensor has the ability to do peer to peer communication, but sometimes the network hierarchy does not allow peer to peer communication. The sensors will send data to the server via a network enabler. The results of the sensor can be viewed via the web or retrieved by other smart phone devices.

E. Add on Application

The use of sensors will depend largely on the development of software applications created by developers on a Smartphone or computer. This is because the number of users of mobile apps continues increase from year to year as shown in the following Table III. Sensor based applications is likely to be a growing option in the future.

TABLE III
USERS OF MOBILE APPS WORLDWIDE BY REGION 2012-2017
ACCORDING TO PORTIO RESEARCH

Description	2012	2013	2017
App users worldwide	1.2 billion	N/A	4.4 billion
Asia Pacific	30%	32%	47%
Europe	29%	28%	21%
North America	18%	17%	10%
Middle East & Africa	14%	13%	12%
Latin America	9%	10%	10%
Source: © Portio Research (March 2013)		via: © mobiThinking	

Examples of the sensor-based applications widely developed is location-based application, take advantage of the compass and GPS sensors installed in the smart phone as shown in Figure 5 below.

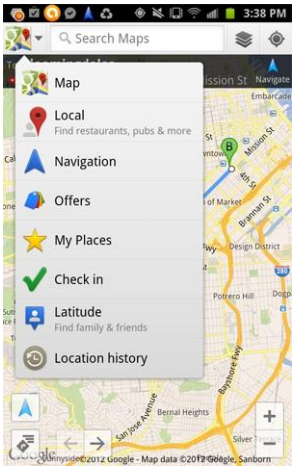

Figure 5: Sample of sensor based apps

F. Special purpose sensor

Implementation of sensor in a specific purpose tools such as unman military or galactic explorer mission also will increase in future. Those sensors will communicate using a specific gateway that is controlled by the server at the command centre.

V. CHALLENGES

Beside all challenges that already mention on [1], new branches of sensor network evolution need to consider additional challenges such as:

- API sensor standardization
- IP Addressing
- End to end security

A. Standardization

Sensor implementation on enabler devices like Smartphone and smart home appliances is hard because the documentation is very limited and because their use is dependent on manufacturer implementations. In the future, Qualcomm wants the industry to come up with common APIs that will support basic sensor functions while allowing companies to introduce proprietary enhancements that can add special features to an application [1].

B. IP Addressing

Given the sensor implementation on a smart phones, smart home appliances and other devices enabler in the future will be required a large amount of unique IP address. It is necessary to think about whether to use the IPv6 addressing or using IPv4 as transition. It also needs to be determined whether the allocation of IP for sensors or for the enabler devices.

C. End to End Security

Due to no end to end security in some public network, such as in 2G/3G Network [12] where security only applied from CPE to BTS, it become user responsibility or application responsibility to develop end to end secure app based on sensor.

VI. CONCLUSIONS

Evolution of the sensor network takes new branches that were not previously predicted. Sensor size become smaller, but more important is the implementation of the sensors tends to be part of the more comprehensive equipments such as smart phones or smart home appliances. In communication point of view, current sensor networks and the future are relying on public communication infrastructure such as 2G/3G/4G. IP based protocol, either IPv4 or IPv6 to be an attractive option for network sensor because it's ubiquitous and adopted by many developers. Sensors application also to be part of personal needs, but development of the apps requires standardization and interoperability in sensor devices. In the future, sensors possibly be developed using a technology that haven't yet imagined today. It may include development of sensor using glass or even biology tissues.

REFERENCES

[1] http://www.fiercedeveloper.com/story/sensor-based-apps-offer-lots-potential-are-hindered-fragmentation/2012-04-20, accessed on October 28, 2013

[2] Chee-Yee Chong; Kumar, S.P, "*Sensor networks: evolution, opportunities, and challenges",* Proceedings of the IEEE, Volume: 91, Issue: 8, 2003.

[3] Freris, N.M. ; Kowshik, H. ; Kumar, P.R., "Fundamentals of Large Sensor Networks: Connectivity, Capacity, Clocks, and Computation," *Proceedings of the IEEE Volume: 98, Issue: 11, 2010*.

[4] http://mobithinking.com/mobile-marketing-tools/latest-mobile-stats/a#subscribers, accessed on October 29, 2013

[5] Samundiswary, P. ; Priyadarshini, P. ; Dananjayan, P., "Performance Evaluation of Heterogeneous Sensor Networks," Future Computer and Communication, 2009. ICFCC 2009. International, 2009.

[6] Mhatre, V. ; Rosenberg, C." Homogeneous vs. heterogeneous clustered sensor networks: a comparative study". Communications, 2004 IEEE International Conference on Volume: 6, 2004

[7] Xueqing Wang ; Shuxue Zhang, Comparison of several sensor deployments in wireless sensor networks , E-Health Networking, Digital Ecosystems and Technologies (EDT), 2010 International Conference on Volume: 1, 2010

[8] Shi Lan; Miao Qilong; Jinglin Du, *"Architecture of Wireless Sensor Networks for Environmental Monitoring"*, Education Technology and Training, 2008. and 2008 International Workshop on Geoscience and Remote Sensing. ETT and GRS 2008. International Workshop on Volume: 1, 2008

[9] G. Spinay, F. Robertsy, J. Weppneryy, P. Lukowiczyy, O. Amft," CRNTC+: A smartphone-based sensor processing framework for prototyping personal healthcare applications", Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2013 7th International Conference on, publication Year: 2013.

[10] Hamilton Turner (Vanderbilt University, USA), Jules White (Vanderbilt University, USA), Brian Dougherty (Vanderbilt University, USA) and Doug Schmidt (Vanderbilt University, USA), "Building Mobile Sensor Networks Using Smartphone and Web Services: Ramifications and Development Challenges", IGI-Global, 2011.

[11] Prawit Chumchu, Attaphon Phayak, "A Simple and Cheap End-to-End Voice Encryption Framework over GSM-based Networks", 978-1-4577-1719-2/12 ©2012 IEEE

[12] Robert LiKamWa†‡, Yunxin Liu‡, Nicholas D. Lane‡, Lin Zhong, "MoodScope: Building a Mood Sensor fromSmartphone Usage Patterns".

[13] Saikat Guha, Mudit Jain, Venkata N. Padmanabhan*" Koi: A Location-Privacy Platform for Smartphone Apps",* NSDI'12 Proceedings of the 9th USENIX conference on Networked Systems Design and Implementation, 2012.

[14] http://mobithinking.com/mobile-marketing-tools/latest-mobile-stats, accessed on October 30, 2013

[15] http://www.expertreviews.co.uk/general/1301596/samsung-smart-home-appliances-are-the-future, accessed on October 30 2013

[16] Unman Aircraft System Roadmap 2005-2030 , http://www.fas.org/irp/program/collect/uav_roadmap2005.pdf, accessed on October 30, 2013