Wireless Sensor Networks in Next Generation Communication Infrastructure: Vision and Challenges

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Abstract. Last decade saw the development of Wireless Sensor Networks with multitude of applications built around the sensors. Though most of the issues at protocol and device level remain solved for Wireless Sensor Networks, there is a growing trend in integration of sensors and sensor based systems with Cyber Physical Systems, Machine-to-Machine and Device-to-Device communication both in infrastructure and ad-hoc modes. The emergence of Cloud Computing, highly intelligent 'Smart' devices and efforts towards 5th Generation telecom systems is expected to lead the revolution of a networked world with increased demand for situational awareness leading proliferation of sensors at the edge of physical world. Mounting intelligence built in 'smart' devices, scarcity of frequency spectrum, disruptive technologies and limitations on further reduction in base station size may render base station centric-architecture of today's wireless networks old-fashioned. Due to low data rate bursty nature of sensor data, massive-MIMO antennas, device-centric architectures, smarter devices and native support for Machine-to-Machine and Device-to-Device communication, sensor data originating from these systems and disruptive technologies is expected to grow manifold through passing years. Communication and network engineers face an emerging challenge of designing communication and network protocols that can efficiently get integrated with the emerging wireless cellular and computing paradigms. In this paper, we list down these communication and networking challenges and provide our vision for Wireless Sensor Networks related platforms and enabling technologies of next decade.

Keywords: Wireless sensor network, cyber physical system, cloud computing, next generation network, seamless integration.

1 Introduction

Over the past two decades, wireless communication and networking has seen rapid advancement with introduction of new standards and protocol that provision short

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range personal communications to large geographical scaled monitoring applications. Significant contributions have been made to protocols related to Wireless Sensor Network (WSN) for applications involving real time as well as buffered data. WSNs provide low-cost, low power, multifunctional miniature devices, with multiple sensory interfaces that gather environment related information (Fig 1) and communicate it in an untethered manner over short distances [1]. Various WSN standards have evolved over the years according to the changes and requirements for sensory environments at different times [2]. More recently, with maturity in WSN and related wireless standards, researchers have started looking into leveraging WSN functionality with more control, interaction and reliability. In terms of interaction between real and virtual environments, Cyber Physical Systems (CPS) and Cloud Computing concept and method has been greatly discussed and included. CPS provides an intuitive mechanism for human-to-human, human-to-object and object-to-object interactions. Quite recently, WSN and similar wireless applications have started to investigate cloud aspects of the system for expanded network connectivity and finer integration. By definition, CPS and related futuristic network technologies provide a system of collaborating and interacting elements with physical input and output intended to provide full remote control giving a feeling of virtual environment instead of a sole standalone system [3] [10].

Currently, CPS and Cloud Computing for WSN have been discussed separately for their features, requirements and challenges while only a vague distinction exists to identify the overlapping areas where both can be seamlessly merged. With this perspective, there is a need to highlight, and emphasize with clear distinction as to where the communication layers for WSN and other network related platforms merge and how the challenges in making the widely distinct operation and functionality be made compatible. The possibility for integration of CPS and Cloud with WSN has also been made somewhat possible with accelerated maturity in wireless technology and embedded computing with applications like micro sensing MEMS, inertial motion detection, bio-signal sensing, environment parameter sensing, location and vehicular movement detection. While a common platform is being sought for merging and connecting common parameters, the main technological distinctions need to be made clear. WSN has been designed and implemented majorly with the perspective of communicating sensing related data with coordination over some limited geographical and a characteristic environment. CPS, on the other hand, utilizes a broader definition and dimension of sensing data over multiple networks with a Cloud specific link to the internet with the aim of providing elevated controlled intelligence [4].

A vast amalgamation of basic sensors has now been connected to a network that has global perspectives. This has thus created a phenomenon where information revolution and an explosion in the expertise to create, store and provide data mining to digital information from these sensors has come about. Wireless Sensor Networks has therefore moved from an early research topic to the pinnacle of sensor application development and deployment. Cloud Computing is the main principle to provide global perspective to the sensor data and is designed and promoted with the sense of being data centric with efficient interaction with the outside world. Though WSNs are designed to collect data in the real world, yet, issues still persist as to provide an automated method to discard or reduce the actually required information that can be analyzed at a later stage. An efficient aggregation method needs to be accompanied

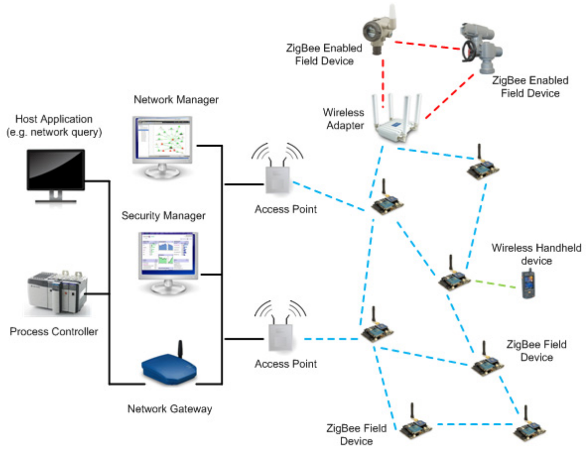

Fig. 1. A typical WSN architecture with network elements

with the Cloud oriented facility to cater this aspect [25]. Keeping this as the main focal area of work, we link real world requirements and industrial standards to provide a likely picture of where the WSN and next generation networks merger would be seen in near future and directions as to how it would be met.

2 Disruptive Network Technologies and Wireless Sensor Network

The use of wireless communication technologies, particularly environment monitoring applications has become ubiquitous due to the freedom of distributed capabilities, and cost savings the technology offers [3]. WSNs have therefore emerged as the next wave of penetrating wireless technology, enabling greatly distributed efficient measurements methods across vast physical systems and environments. With WSNs, one can effectively analyze and examine everything from infrastructure health and forests to the health and safety of living beings. The ability of WSN to allow use of spatially distributed measurement devices that utilize sensors to monitor physical or environmental conditions has provided an open platform wherein rapid applications and implementations are emerging [26]. In addition to many wireless measurement nodes, the WSN system may include several other nodes like gateway, relay and aggregators that collects data and provides connectivity back to a remotely hosted application on a Cloud or some monitoring station or even an automated embedded controller [27].

2.1 Wireless Sensor Networks with OpenFlow Technology

To enable implementation of vast protocols and emerging applications on the basic sensor platform, the OpenFlow technology concept has created another intense research dimension. The OpenFlow platform can basically provision splitting the traffic path into a data packet that is maintained by an underlying router or switch and the other being the control packet that would be maintained by a controller or control server itself. The controller would turn the physical sensor device into a much simpler one instead of a complicated mode since major complex intelligence related to basic programs and system level codes are removed. So, the platform becomes easier for the researchers to investigate and examine under different experimental traffic, various protocols and overall network would be simplified as well as being more advanced in terms of application support. The use of open platforms with WSN is the current need and it is much expected that in near future these research will lead to a momentous achievement in sensor network modernization [1]. The OpenFlow method can be very useful in this regard since from attainable throughput and feasible result viewpoint for sensor network and other platform integration, the amount of traffic and header definition rate is reasonably low and almost insignificant [11]. A FlowVisor device has been defined in the architecture that is basically a software-defined networking controller that enables network virtualization by slicing a physical network into multiple logical networks (Fig 2).

Fig. 2. A typical WSN implementation with OpenFlow technology

OpenFlow for sensor networks is one of the most debated topics now a day since none has ever tried this protocol extensively on wireless sensor networks till date. OpenFlow based sensor network, is generally claimed to be much more reliable and flexible in comparison to typical sensor node since data packets, control packets, data route and even the sensor nodes themselves can be easily experiential, synchronized and routed whenever required. The system can be considered a fully centralized system from physical layer viewpoint but a distribution of services related to the sensing information are still maintained. A central system can be used to monitor and control all sorts of sensor traffics. This can help to achieve a better data rate, bandwidth efficiency, reliability, robust data routing. Ultimately this will lead to a better QoS provision for the monitored environment. But presently the sensor devices are mainly vendor oriented and individual software applications need to be maintained that present a lack of service coordination [11] [12]. By use of

OpenFlow inside sensor network domain allow can start and stop of traffic whenever required through a central coordination system.

2.2 Consistent WSN Application Development

Consistency of WSN application is one of the most requisite factors and difficult as well to achieve for these sensor nodes due to their short resources and communicational abilities. In the current innovations, the management and maintenance of the unstructured sensor devices with connection to the undetermined and uncertain number of wireless sensor nodes and their establishment in harsh and tough terrains and areas has provided a major implementation challenge. The sensor network can be dynamically self-structured and self-constructed and the nodes within the span of the network must possess the ability to deliver and maintain mesh connectivity at all times [13] [14]. As seen from a message transfer view point, hop to hop, node to node or end to end reliability issues and challenges are still unsolved. Several innovations have tried to work with reliability limits or to obtain partial reliability. It is noted that there is always a compromise with the reliability and total reliability has been proven to be almost impossible for all major wireless networks. So, it's beneficial to use various platforms for transporting sensor flows where traffic can be remotely controlled and sensor nodes can be monitored remotely. Currently different protocol changes and applications for sensor network are being experimented and supported by several major switch/router vendors that provide a set of functions which may be common at some point but support all sort of OSI layer headers. These technologies including simulators for senor network can provide a single platform for typical TCP/IP implementation and cross layer experiments. It will also be able to allow integration of the circuit and packet switching related technology and applications. Further these applications can be treated separately too. The core sensor network also gains noteworthy benefits due to control, management related policies and cost benefits including much needed energy effectiveness and overall better network performances and data gathering and aggregating capability.

3 Architectures for Future Sensor Network Deployment

The structured WSN deployment simplifies the routing protocols and increases efficiency and cost-effectiveness of the network. A hierarchical structure of monitoring case based on WSN allows the basic functionalities to be distributed among the nodes [22]. The nodes at the lowest level are the sensing nodes that sense the parameters from the environment Relay nodes closer to sensing nodes collect sensed data and pass it on to data dissemination nodes which finally transmit the data over long haul communication link to the control center (Fig 3). The advantage of such a topology is that it adds redundancy to the whole architecture while reducing the range of each node that ultimately induces low energy consumption. The functionalities of nodes on each level can be made distinctively diverse so as to make the data collecting system more intelligent. The CPS architecture resembles traditional embedded systems that aim to integrate abstract computations with physical processes. Contrary to traditional embedded systems, CPS provides an interconnected interactive with output and input that pertain physical existence and are standalone devices. The main layers of CPS are the virtual layer and physical layer. For the physical layer, an intelligently deployed network of actuators and sensors collect information and actually control the physical world. By converting the analog information into a digital format, the information is sent to a virtual layer input which serves as the decision making setup. This information is further used to calculate abstract computations that feed into the real world actuation system to drive and control physical world output.

In contrast to CPS, the WSN architecture focuses more on node design and inter-node communication and networking. In WSN, the node converts measuring metrics from various environment monitoring sensors related to physical, biomass and chemical parameters into digital information to be read and inferred by a remote monitoring facility. By application perspective, we can classify important hardware resources in WSN node as the Sensing Unit, Processing Element, Transceiver Device and Power Manager. The communication and networking for WSN needs to handle joining and leaving of hundreds of nodes while providing scalability. Current research involving data transportation adds re-configurability to nodes and manipulating the hardware during run-time and designing nodes such that they consume extremely low power.

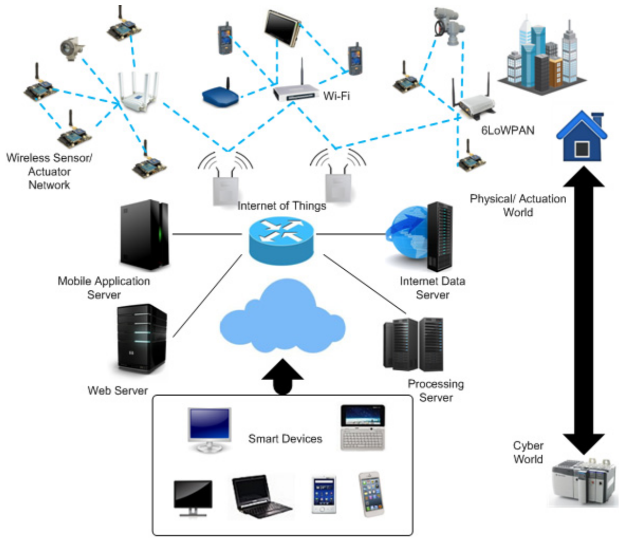

Fig. 3. WSN architecture integration with different platforms

3.1 A Virtual Sensor Infrastructure

Cloud computing services for wireless networks can provide virtual servers. Users can use the remote servers with no concern as to where the server is located and how much resource specifications it can provide [15]. The cloud computing infrastructure for sensor networks can provision virtualization for multiple physical sensors as 'virtual sensors' (Fig 4). For examples if there are multiple temperature sensors for building monitoring application, a set of sensors could be defined as virtual sensors for each floor providing a direct map for the monitoring area division. In a sensor cloud application, the users or nodes should be able to control virtual sensors with standard functions. Dynamically grouped virtual sensors can be used to provision automatic responses to different requests. The user of the sensor application should also be able to destroy the virtual sensor setting once it is no longer required, hence it should be provisioned with flexible formation and removal.

Monitoring virtual sensors would elevate the quality of service for wireless monitoring applications. The sensor cloud infrastructure needs to have a user interface either at the site or through some remote setup whereby the adding or deleting of physical sensor the cloud can be performed. Other functions for virtual sensors should include request, controlling, monitoring and registering different allowed functions for the specific sensors or sensor nodes.

For designing the virtual sensor system, a platform is required wherein the functionality of the virtualization is defined encompassing relationship between sensor groups, virtual sensors and physical sensors. Different types of sensors would have different specifications, so in order to create a virtual environment with different sensors, standardization method would be required. This also accounts for the automation process for the sensor network relating to hardware as well as software operation. A continuous monitoring system should be deployed that would confirm the division between the virtual and physical systems. Grouping sensors can cause several challenges, for example when setting the frequency of reporting from a group of virtual sensors, different sensor nodes would have different capabilities and ma not respond evenly, hence a mechanism for controlling the commands and its manipulation in a group is required. Defining a service model for the sensor cloud can provide different sensors as a service for a particular application. Finally the division between sensor owners and cloud administrator is required.

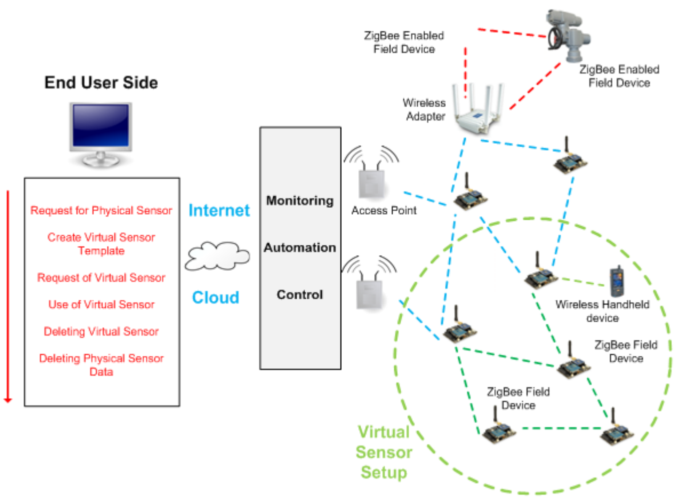

Fig. 4. A virtual sensor cloud infrastructure example

4 Future Wireless Sensor Network Applications

For monitoring remote WSN applications over the IP framework, cloud computing can provide a middleware cost effective solution to both domains that provisions a rich interactive communication platform. Since network communication costs a lot of bandwidth overhead for linking VMs in data intensive environments, a decentralized approach, where migration of VM services is provided with monitoring of traffic fingerprints can relieve the wasted overhead. Also, in particular cases, faults can occur in the middle of a query from distributed databases. This can be fixed by dividing queries into subqueries and mapping them in an intelligent way such that the results return on different nodes. In CPS, location for different data generating and terminating points serve as a first class knowledge for many applications. As compared to outdoor location detection through GPS and similar approaches, indoor location estimation or localization proves more challenging [5]. Proposed systems relate to smaller scale environments while to cope up with newer demands of extended scaled up systems, pattern matching of data can be applied as a useful solution.

CPS provides a bridge to link the cyber world with communication, intelligence and information components and the physical world counterpart providing sensing and actuation capabilities [6]. The CPS platform may be broadly classified as an integration of intelligent control design system with the mobile or static sensor or actuator system [23]. When considering individual WSN networks, issues like network formation, security, mobility and power management remain almost the same on a broader perspective [16]. However, major advanced technical differences from the WSN approach include the use of heterogeneous information flow, multi dimensional sensor cooperation and high level of intelligence and algorithm behind the actuation and decision framework [24].

From the applications point of view, CPS holds a wide range of useful features that can be used to provide elevated services to users with a wide range of implementations. For example, CPS can be used in cooperation with WSN to assist in management of greenhouse sensing information at large geographical distances. More complex system would include multiple sensors and actuators that can be used for applications such as environment related climate control settings with humidity, heating, carbon dioxide generation, fertilizing and watering system features.

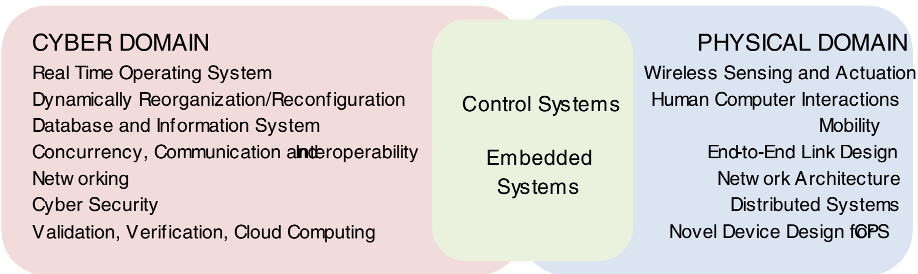

Fig. 5. Overlapping areas for cyber and physical worlds in sensing platform

4.1 Device Specifics for Future Sensor Networks

Sensing devices in the WSN are basically organized and placed with a data processing unit and communicational abilities that are required to measure the specific parameters from the surroundings and convert those parameters into relevant analyzable form. These kinds of sensing devices can significantly raise the effectiveness of both the environment conditions and general information data base for inspection, safety, and failure management. Also it is useful where usual and normal data access attempt have proved to be very expensive and uncertain. Unstructured wireless sensors also have the capabilities to observe and collect a large amount of environmental conditions such as sound, pressure, motion and temperature etc. These sensor nodes consume resources such as a small bandwidth, processing power, communication range, memory and capability. The processing of signals and communication activities are felt to be the significant factors to improve the data relay capabilities and reliability turns better thereby [18].

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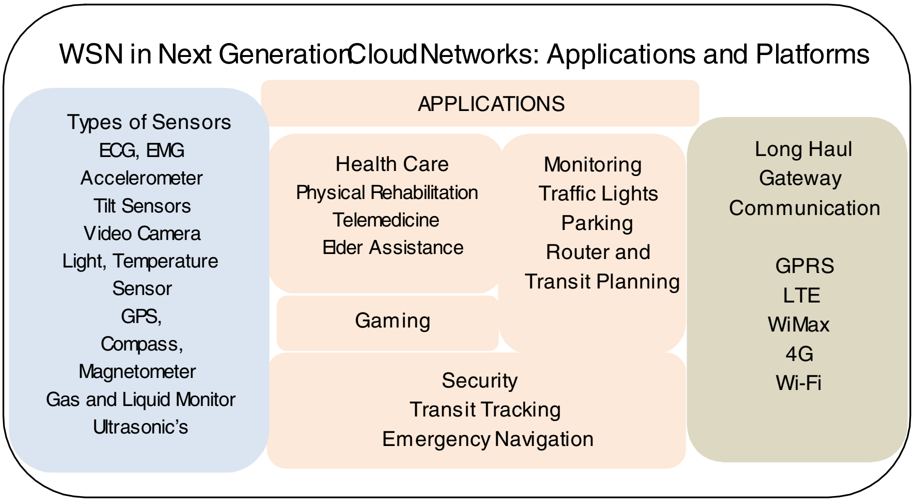

Fig. 6. Applications and platforms for Wireless Sensor Network in Cloud Computing infrastructure

location detection through GPS and similar approaches, indoor location estimation or localization proves more challenging. Proposed systems relate to smaller scale environments while to cope up with newer demands of extended scaled up systems, pattern matching of data can be applied as a useful solution. CPS for WSN provides a bridge to link the cyber world with communication, intelligence and information components and the physical world counterpart providing sensing and actuation capabilities. The CPS platform may be broadly classified as an integration of intelligent control design system with the mobile or static sensor or actuator system. When considering individual WSN networks, issues like network formation, security, mobility and power management remain almost the same on a broader perspective. However, major advanced technical differences from the WSN approach include the use of heterogeneous information flow, multi dimensional sensor cooperation and high level of intelligence and algorithm behind the actuation and decision framework [17] [19] [20].

5 Issues and Challenges

The massive deployment of WSNs in future platforms is expected to increase exponentially in the next few years, thus allowing millions of wireless devices to work autonomously for newer applications and platforms. These next-generation WSNs are also expected to interact with other devices such as Radio Frequency tags, home appliances, mobile equipment and automobiles [28]. When integrated with the cloud and similar platforms, these sensor networks could provide ubiquitous and pervasive services to the users by providing unlimited and powerful storage infrastructure. The current challenges for next-generation WSNs are scalability, resource scarcity, heterogeneity, decentralization and dynamicity. These challenges and requirements cannot be fulfilled by traditional WSNs and related approaches. In addition, the Network, Medium Access Control (MAC), and Physical (PHY) layer protocols developed for traditional WSN platforms [7] are not applicable to the next-generation WSNs, where thousands of battery-powered nodes need to be operated for longer durations. Said otherwise, the next-generation WSNs require the development of novel and innovative protocols at each layer that must be able to extend the network lifetime from months to several years. These protocols may allow seamless integration of next-generation WSNs and similar platforms with other networks and platforms including internet of things and cloud computing [29].

5.1 Data Reliability

Data consistency and reliability becomes much complex when WSN is viewed from a CPS perspective [21]. Major reliability design requirements for implementing a well planned CPS include 1) Service oriented architecture (SOA) 2) QoS aware communication and networking 3) intelligent resource management and 4) QoS aware power management at different networking levels. Service oriented architecture plays an important role in reducing the complexity of the overall infrastructure by decomposing CPS functions into smaller distinguishable units each viewed as a separate service. This allows rapid, efficient and scalable development of a CPS application through reusable service units. Application level QoS however needs to be defined for intelligent cross layered communication while in future, linking WSN with CPS environments would greatly require dynamic system settings for unpredictable environment. Self management policies would be needed so that allocated resources like CPU time, bandwidth memory, energy profiles to be controlled intelligently in a high level QoS constrained setting. Major concern with high level reliability provisioning always pertains to the minimization of energy consumption for major network elements. In this regard, cloud computing provides a possible solution wherein two major enabling technologies for this setup are virtualization and ubiquitous connectivity. Virtualization related technological methods allow provision of dynamically changing and altering resources based upon service isolation thus enabling scaling and managing of resources in more controlled way. With the addition of different payment levels for service variations and on-the-go routine, the cloud computing services can be classified under (1) Infrastructure as a Service (IaaS) (2) Platform as a Service (PaaS) (3) Software as a Service (SaaS). IaaS generally provides isolation between lower layers generally termed 'real machines' for use in the user oriented cloud infrastructure.

5.2 Web Enablement for the Cloud

Use of web access approach enables the integration of different networks into the internet with provision of user friendliness and platform independence. Enablement of the web for sensor network applications can be supported by HTTP over either TCP or UDP. Despite having overhead related to congestion control and flow control, HTTP/TCP is more suitable sine it provides interoperability. For HTTP/UDP however, there would be a requirement of an additional component at the sensor network border or gateway that will play the role of a TCP-UDP translator. Though the gateway can perform the role of a translator, the protocol differences may cause problems such as inconsistency, redundant transmission and delays. The draft of the IETF CoRE WG proposes to use HTTP over UDP where connection related response and requests can be packed into a single UDP connection and packets may be delivered using multiple datagram's. The condition associated with use of multiple datagrams is the support for fragmentation and reassembly at the end connection side. Hence the system might not be suitable for sensor networks that provide rich content delivery and multimedia data. This approach will also cause unnecessary retransmissions because a renewal command is sent at the higher level application, the backend languages like CSS, HTML and Javascript need to perform compatible actions. Hence a design choice needs to be decided for enabling effective web enablement solution for sensor networks reporting to remote locations and how future networks would be integrated smoothly into the IPv6 system.

5.3 Quality of Network Service

Prediction of accurate output decisions and reliability of sensing information are considered critical for CPS systems. These factors also form the Quality of Service (QoS) basis for achieving a real time intelligent system for high stress and constrained environments like mining, healthcare and warfare [8]. The real challenge lies in maintaining QoS factors like seamless flows and timely delivery and when CPS is integrated with other technologies like semantic agents and hybrid states. Deployment of CPS architectural parts require placement of sensing and actuator devices at strategically critical points with intelligent algorithms for node localization and geo-location detection. The Medium access control (MAC) should cater that the negotiation between neighboring data collection devices and sensors must conserve resources like bandwidth, number of channels, buffer storage and transmission energy [9].

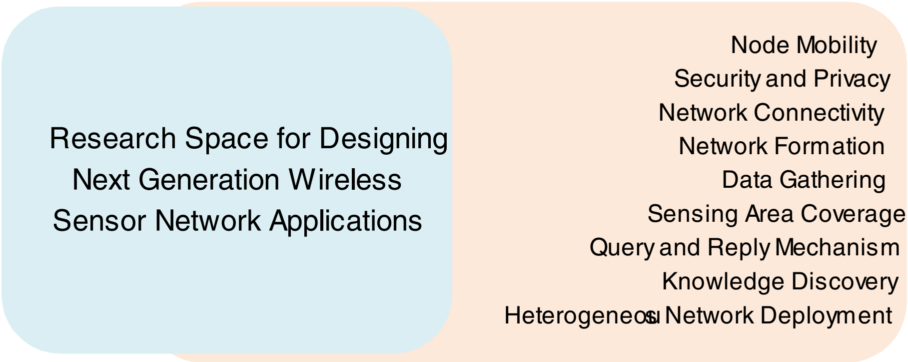

Fig. 7. Research Space for designing future Wireless Sensor Network applications

6 Conclusion

While the domain of WSN focuses more on the designs for sensing, data-retrieving, event-handling, communication, and coverage problems, CPS community focuses more on the development of cross-layered and cross domain intelligence from multiple WSNs and the interactions between the virtual world and the physical world. A CPS application may provide a bridge between multiple remote WSNs and invoke actuation based on inference from the sensed information. A lot of successful vehicle- and mobile phone-based CPS services have been developed over time. Data from such applications may be expected to be of continuous form at a very large volume, so storing, processing, and then intelligent interpreting of it in real-time manner is essential. Important factors to the success of CPS include management of cross-domain sensor related data, embedded and mobile sensing technologies and applications, elastic computing and storage related technologies with integrated privacy and security designs. We have also reviewed different platforms for environment monitoring, navigation and rescue services, ITS, social networking and gaming with related challenges in these systems. The specifics of future WSN platforms are expected to stimulate an interested reader with current CPS technological development and expected features of future enabled WSN platforms.

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