19th International Conference on Knowledge-Based and Intelligent Information and Engineering Systems

Cognitive Network Framework for Heterogeneous Wireless Networks

Ahmed Al-Saadi[a,b], Rossitza Setchi[a], Yulia Hicks[a]

[a] School of Engineering, Cardiff University, Queen's Buildings, Cardiff CF24 3AA, UK
[b] Department of Computer Engineering, University of Technology, Baghdad, Iraq

Abstract

The Internet is used by more than two billion customers around the world and is expected to serve as a global platform for interconnecting cyber-physical objects that form the Internet of Things (IoT). Within the next decade, traffic demands are expected to increase a thousand-fold. This challenge can be addressed by introducing and expanding heterogeneous wireless technologies, which provide higher network capacity, wider coverage and higher quality of service (QoS). However, the heterogeneity and complexity of these networks are a major challenge for traditional control and management systems. Therefore, there is a need for self-manageable and self-configurable networks that support the data produced by the different IoT devices and provide opportunities for data analytics. In this work, a cognitive network framework is proposed, in which the network protocol stack is integrated with a semantic system. The proposed framework provides the bases for building smart networks that observe data from different layers in the network protocol stack and represents it in a hierarchical structure in a knowledge base. The framework employs an ontology that provides an abstraction model for the different heterogeneous wireless devices. The ontology determines the relationships between technology-dependent parameters in the network protocol stack and enables, through the use of inferences, the utilization of the observed data from the network. The use of a cognitive network framework with the network protocol stack allows adding ontologies to describe the data, a solution which could solve the problem of analysing, searching or visualising data.

Keywords: semantics; ontologies; heterogeneous networks; next-generation networks; IoT

1. Introduction

In the 2014 annual digital universe study, International Data Corporation (IDC) announced that in 2013, only 22% of data produced by the Internet was eligible for analysis (the data is useful if it is characterised or tagged)[1]; furthermore, only 5% of this eligible data are well tagged and could be analysed. The Internet of Things (IoT) is an

extension of the existing Internet architecture and serves as a global platform of interconnected physical objects or 'things' to enable a new way of working, interacting and living. IoT applications include many fields such as industrial and urban sensor networks. The number of physical things in the world already far outnumbers the number of people. This creates new challenges in terms of integrating IoT with the Internet as the Internet architecture needs to serve much more traffic due to the new demands introduced by the connected physical things. The integration of the physical world requires self-configured networks in which the physical devices take decisions without the assistance of human beings.

Wireless communication plays an essential role in interconnecting the physical entities and provides an infrastructure for the future of the Internet. However, wireless communication suffers from the lack of available radio spectrum, limited capacity and interference. During the past few years, the traffic demands in mobile wireless networks have witnessed enormous growth due to online games, video conferences and online TV, which will overload the current capacity of wireless networks.

In order to meet the massive growth in traffic demands, network operators need to add more wireless nodes or provide new spectrums. Utilizing more nodes with multiple heterogeneous wireless technologies is of the means of perusing more dense networks and providing more spectrums. One promising wireless technology is long term evolution (LTE) [2], which is an evolution of the 3G standard and could provide a high transmission rate up to 326.4 Mbps with a wide coverage. Many mobile operators are adopting LTE networks to provide high-speed Internet service to their clients. However, LTE could suffer from poor performance at the edge of the cells, inside buildings or in crowded areas, which causes high uplink traffic. Another wireless technology is the IEEE 802.11, commonly known as Wi-Fi [3]; it provides low-cost, convenient and high transmitting speed technology. Wi-Fi has already been deployed in many hotspots, including airports, libraries, coffee houses and hotels. Compared to LTE, Wi-Fi uses unlicensed frequency bands, which means it is not necessary to pay for bandwidth; however, this attribute also increases the possibility of interfering with other neighbouring networks. Wi-Fi provides better indoor coverage, and the chipset price for Wi-Fi is dropping continuously, making it an economical networking option which is being included in more and more devices. Wi-Fi offers a data rate up to 780 Mbps in the new IEE802.ac, and the bandwidth is device-to-device transmission. Thus, each device utilises all the available bandwidth to transmit the incoming traffic by using carrier sense multiple access with collision avoidance (CSMA/CA) as a medium access control. However, Wi-Fi networks suffer from the lack of available spectrum, interference and collision.

In order to face the surging data requirements, it is necessary to effectively utilise the existing wireless technology, such as LTE and Wi-Fi, to provide greater capacity and better service to the end user. The heterogeneity of the wireless technologies, standards and data formats make the interoperability of such a complex system a very challenging problem. In this work, a new cognitive framework to model the heterogeneous wireless network is proposed. The aim of the proposed cognitive network is to provide a general framework for the heterogeneous wireless network that is easily expandable to add new wireless technologies and new sets of rules to reuse the available knowledge in optimising the wireless network. The framework employs ontologies to provide an abstract model for the components of heterogeneous networks. In addition, a set of rules is developed to be utilised by the inference engine to allow different types of reasoning on the knowledge base. The proposed framework employs ontology to create relations among the technology-dependant features, and then an inference engine utilises the knowledge to infer the appropriate action based on a set of predefined rules. The cognitive framework is connected with each layer in the ttransmission Control Protocol/Internet Protocol (TCP/IP) protocol stack and observes parameters from each layer. Therefore, it is possible to describe low-level networks operations, like routeing, managing heterogeneous transmission technology or characterising application layer data. Ontologies enable networks to enrich and unlock data through exploring the different relationships between different data. The proposed framework has the potential to be extended for describing and storing the data such that it is interpretable by computerised machines by using reasoning system on the knowledge base.

2. 2. Related Work

This section reviews advanced approaches to employing ontologies and knowledge engineering in wireless networks. It first highlights the use of semantic technologies and ontologies in networking and wireless communication. Then it review the methods to manage heterogeneous wireless networks.

Ontologies and semantics have many applications in wireless sensor networks (WSNs). The data produced by the WSNs are employed to build ontologies [4-14] by observing the values from each sensor and building ontology to assist in the routing protocol to select the next hop to the sink node [4, 5], or building service-oriented architecture ontologies for service advertisement and discovery [5-11]. One of the major problems in WSNs is power control; semantic web technologies are utilised to reduce the amount of consumed power in sensor nodes by detecting idle nodes and putting them in sleep mode [12, 13]. Ontologies are also employed in managing roaming among different networks to solve the problem of creating service-level agreement among different network operators [14]. The work reviewed focuses on employing the service provided by the network to create the ontology and use it to improve network performance. The work proposed in this paper, however, develops a new cognitive network framework to model each component in a heterogeneous network environment and create an ontology structure of the attribute in each transmission technology that forms the network. Then, a set of properties and relationships among heterogeneous network components is formed in order to provide a general abstract model for the heterogeneous wireless network.

The related work reviewed also demonstrates the benefit of using heterogeneous wireless networks and the state of the art networks. One of the key requirements for the 5G network is the use of different technologies in the network, particularly LTE and wireless local area network (WLAN), and solutions have to work out whether the wireless devices are located on the same node or not [15]. Some heterogeneous networks have employed broadband networks, such as cellular, LTE or WiMAX with Wi-Fi WLAN. One approach is for the Wi-Fi access points to utilise the LTE network as a backbone to access the Internet [16]. A second approach is to employ the Wi-Fi network for indoor communication and the LTE network for outdoor communication [17, 18]. Further work on heterogeneous networks is presented in [19], where a load-balancing node is employed to distribute the load on two different networks. Finally, a heterogeneous network's WiMAX / Wi-Fi management system is developed in which the Wi-Fi network is employed to offload the WiMAX network that provides wider coverage [20, 21 and 22]. The work in [20] proposes a management system that manages the WiMAX network and collects statistics about the Wi-Fi network. In [21], the WiMAX network controls the bandwidth request confirmation for the Wi-Fi network and eliminates the need to send control messages through Wi-Fi networks.

Heterogeneous ad hoc networks are another type of heterogeneous networks that combine different wireless medium access control (MAC) such as IEEE 802.15.4 (ZigBee and IPv6 over low power wireless personal area networks (6LoWPAN)), Bluetooth low energy (LE) and 802.11[23].IEEE 802.15.4 based technologies and Bluetooth LE are utilized to create personal area networks for nodes with limited power supplies and simple processors as these technologies provide low-rate and low-power transmission. The IEEE 802.11 provides the backhaul for sensor networks to propagate data to the Internet.

The use of heterogeneous wireless technologies in next-generation networks improves the overall performance of the network by providing more spectrums and splitting the load on different networks [17-19]. Each transmission technology utilises different standards and data formats; therefore, employing different wireless technologies in one network is a very challenging problem. Thus, networks need to be self-configurable and intelligent to manage the heterogeneity in different wireless technology to deal with adding new transmission devices. The proposed cognitive network framework combines knowledge engineering and artificial intelligence (AI) techniques to represent, integrate and reason upon the features of each network device to automatically manage the heterogeneous node, such as selecting the transmission technology. The framework includes three parts: 1) the knowledge base which forms a hierarchical representation of the network and the relationship among each transmission device; 2) the set of relationships among the parameters of each transmission device and 3) the inference engine which is represented by a set of rules to reason upon the relationships defined in the knowledge base.

3. System Model

This section introduces the network model for the heterogeneous network. The network employs the following types of nodes: the network nodes (Net_Nodes), the user nodes (User_Nodes), mesh gateway (meshGWs) and LTE base station (eNB). Fig. 1 shows an example of the network model for the heterogeneous network. The Net_Nodes are specialised nodes that form the infrastructure for the heterogeneous networks. Each Net_Node is equipped with multiple wireless technologies, including LTE and Wi-Fi. The Net_Nodes utilise the broadband technologies like

LTE to provide a one-hop route to the Internet, while a Wi-Fi device is employed to form a WMN which is connected to meshGWs to provide Internet to the users. The meshGWs are a set of nodes that are equipped with a Wi-Fi device and high-speed connection to the Internet (usually a wire connection). The last part of the heterogeneous network is the User_Nodes. This set of nodes could include smart phones, laptops or any other computerised devices that the users utilise to request service from the Internet or internally from the network. Another type of User_Nodes is a set of objects with embedded technologies to interact with the internal states or the external environment. These objects form what is known as the Internet of Things (IoT). UserNodes could be equipped with one or more of the transmission technologies. The cognitive network framework utilises ontologies to build a hierarchical structure for each transmission technology and form relationships among the heterogeneous wireless parameters. Extensible mark-up language (XML) is employed to build the ontologies for the semantic framework. The proposed framework utilises XML instead of standard ontologies languages, such as ontology web language (OWL) [24], resource description framework (RDF) or RDF schema [25], for two reasons. Firstly, XML is platform independent, which means it could be deployed on any smart phones, personal computers or computerised objects. Secondly, the proposed semantic framework does not need to implement all the functionality that is implemented in OWL or RDF which could exhaust wireless node resources, especially nodes with limited power and processing capabilities.
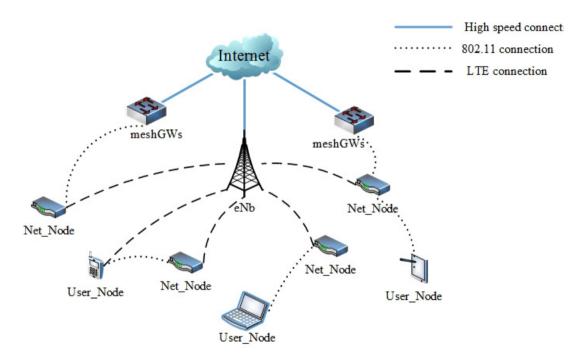

Fig. 1 Heterogeneous mesh network

4. Cognitive Network Framework

In this work, a cognitive network framework is proposed to provide a hierarchical representation of the heterogeneous mesh network. The framework utilises cross-layer information for each transmission device installed on the wireless node and creates a set of relationships between these parameters. Figure 2 shows the block diagram of the proposed cognitive network framework and how it interacts with the different layers of the network protocol stack. The semantic system consists of four parts, the management, the heterogeneous network ontology, the knowledgebase and inference engine. The way the semantic system connects with the protocol layers allows adding or extending the ontologies to represent more application-level data. In this work, the developed ontologies represent the low-level information of each transmission device installed in each node. This information is utilised to forward packets from the User_Nodes to the Internet and vice versa.

The first part of the proposed framework is the management system, which receives data from multiple layers in the network protocol stack, then creates instances of the heterogeneous network ontology in the knowledge base. The management system consists of four subsystems, as shown in Figure 3. The interface subsystem provides a shared boundary between the network protocol stacks and the ontology system. It is responsible to detect the type of network devices installed on the node and to observe link quality characteristics for each device. It also receives information about the neighbouring nodes and declares whether or not the node is part of the network infrastructure (Net_Node or User_Node). The second part is the service type subsystem, which defines the type of service the clients request from the network, such as accessing the Internet or connecting sensing objects as a part of the IoT. This part makes it possible to extend the framework to describe the services of the network and provide metadata for analysing network data. Thirdly, the billing subsystem calculates the cost and the discounts for each User_Node based on the requested service. The last subsystem defines the method to access the services that the heterogeneous network provides. Service-oriented architecture is utilised to access the services provided by the network; more specifically, simple object access protocol (SOAP) [26] is employed as a web service to access the services from the upper layer. SOAP utilises XML to exchange messages between clients and servers. It is thus platform independent,
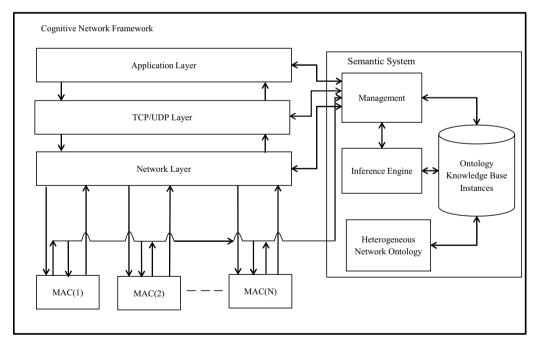

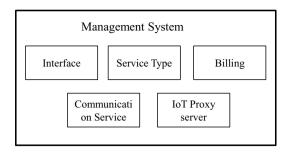Fig. 2. Cognitive network framework

Fig. 3. Management system block diagram

which solves the platform heterogeneity of the devices accessing the network.

IoT networks employ sensor nodes with limited power supplies and simple processors. To control the communication among these constrained wireless nodes, some mechanisms are needed for managing messages exchange. Machine-to-machine/Internet of Things (MQTT) [27] and constrained application protocol (CoAP)[28] are promising mechanisms for controlling communication in IoT sensor networks. MQTT is a client/server model originally developed by IBM for lightweight machine to machine communication. CoAP is a document transfer protocol similar to hypertext transfer protocol (HTTP) designed specifically for devices with limited resources which employs much smaller packets compared to HTTP.

IoT proxy is needed to bridge data from the IoT sensor networks to the web service, this is because of using CoAP protocol to manage data exchanging for sensor nodes with limited resources. The reason of using CoAp in IoT network is that CoAP causes less overhead than HTTP protocol by using smaller packet size and employing user datagram protocol (UDP). CoAP is designed to easily bridge to HTTP protocol and it simplifies the integration with the service oriented architecture proposed in this work [29].

The second part of the proposed framework is the heterogeneous network ontology. As defined in [30], ontology is 'a specification of a representational vocabulary for a shared domain of discourse'. It provides a formal representation of type, properties and relationships among data in a given domain. In this part of the framework, conceptual representations of each device and services are defined. The ontologies define a set of classes, subclasses and relationships. These classes and relationships do not need the expressiveness of ontology languages like OWL, but can instead be defined using simpler expression in XML language. XML is machine readable and could deploy directly on any platform. Figures 4 and 5 show examples of the hierarchical representation of the heterogeneous network using ontologies classes, subclasses and properties. The ontologies defined in this work are employed to describe the heterogeneous nodes in terms of the installed hardware and define link quality characteristics.

The next part of the framework is the knowledge base. It represents the instances of the ontology that describe the heterogeneous network. When the network starts exchanging data and control packets, the interface subsystem in the management system observes the parameters of each device installed on the node, extracts information from the control messages and creates an instance of the ontology in the knowledge base. The information that each node stores in the knowledge base includes the type of each device, the IP and physical address of each device, and quality characteristics about each device, such as transmission power, transmission rate and load on the device. Figure 6 shows an excerpt of the XML for the heterogeneous network for the ontology and the knowledge base. The service subsystem is responsible for creating the instance of knowledge base for the ontologies that describe some services of the network. This part provides the extendibility for the framework to describe the data of the network and also provides the necessary tags to the data for further analyses in the IoT applications.

The last part of the semantic framework is the inference engine. In this part, a set of rules is defined and the inference engine utilises these rules in conjunction with the relationships defined in the ontology and the data in the knowledge base to infer the next action in the network based on the state of the heterogeneous network and the requested service. The rules defined in this work are employed in selecting the transmission device to offload LTE network when the cell is congested.
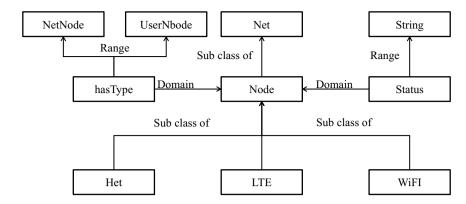
Ahmed Al-Saadi et al. / Procedia Computer Science 60 (2015) 216 – 225

Fig. 4 Ontology graph of heterogeneous wireless network
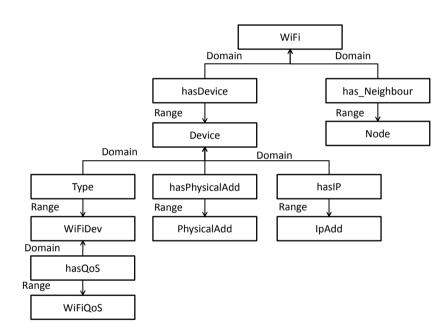
Fig. 5 Ontology graph of Wi-Fi device

a
```
- <Onto>
    <class neme="net"/>
  - <class name="Node">
      <subClassof resource="net"/>
    </class>
  - <class name="LTE">
      <subClassof resource="Node"/>
    </class>
  - <class name="WiFi">
      <subClassof resource="Node"/>
    </class>
  - <class name="Het">
      <subClassof resource="Node"/>
    </class>
  - <class name="Neib">
      <subClassof resource="Node"/>
    </class>
  - <dataProperty name="status">
      <domain resource="Node"/>
      <range resource="string"/>
    </dataProperty>
    <class neme="userNode"/>
    <class neme="netNode"/>
  - <objProperty name="hasType">
      <domain resource="Node"/>
      <range resource="userNode"/>
      <range resource="netNode"/>
    </objProperty>
    <class name="Device"> </class>
  - <class name="LTEDevice">
      <subClassof resource="Device"/>
    ...
    ...
```
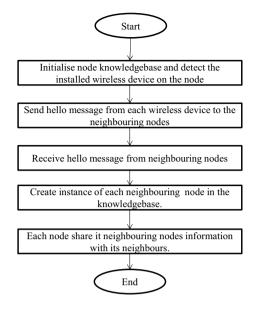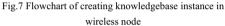
b
```
    ...
        <hasIpAddress>3.0.0.9</hasIpAddress>
        <hasMAC>03-06-00:00:00:00:00:18</hasMAC>
      </hasWiFiDevice>
    - <hasLTEDevice value="true">
        <hasIpAddress>7.0.0.5</hasIpAddress>
        <hasImsi>4</hasImsi>
      </hasLTEDevice>
      <hasNeighb/>
  </individual>
- <individual resource="Node" mine="false" id="13">
      <hasType>netNode</hasType>
    - <hasWiFiDevice value="true">
        <hasIpAddress>3.0.0.10</hasIpAddress>
        <hasMAC>03-06-00:00:00:00:00:19</hasMAC>
      </hasWiFiDevice>
    - <hasLTEDevice value="true">
        <hasIpAddress>7.0.0.6</hasIpAddress>
        <hasImsi>5</hasImsi>
      </hasLTEDevice>
      <hasNeighb/>
  </individual>
- <individual resource="Node" mine="false" id="14">
      <hasType>netNode</hasType>
    - <hasWiFiDevice value="true">
        <hasIpAddress>3.0.0.11</hasIpAddress>
        <hasMAC>03-06-00:00:00:00:00:1a</hasMAC>
      </hasWiFiDevice>
    - <hasLTEDevice value="true">
        <hasIpAddress>7.0.0.7</hasIpAddress>
        <hasImsi>6</hasImsi>
    ...
    ...
```

Fig. 6 XML excerpt of (a) for the heterogeneous network and (b) instance of the knowledge base

5. Network Simulation and Knowledge Base Initialisation

In this section, the cognitive framework is evaluated using the NS-3 simulator [31], which is a widely used tool for evaluating and validating wireless networks. A network scenario consists of an LTE eNB node, 30 nodes of Net_Nodes with LTE and Wi-Fi transmission technology installed on each node and 20 UserNodes with LTE and Wi-Fi installed on each node. The network starts by creating an instance of the knowledge base for each node and then a control message is sent via LTE transmission technology to each node to create and update the nodes instance in the knowledge base. The flowchart of creating the knowledge base in each node is shown in Figure 7. Firstly, the management system in the semantic system employs the interface system to detect the node type (Net_Node or User_Node) and the wireless devices installed on the node. This information is piggybacked on a hello message and then each node periodically transmits the message to the neighbouring nodes. In the LTE network, the base station is one hop away from all nodes in its cell coverage. Each node shares the information of its neighbouring nodes with its neighbours. This results in creating a knowledge base in each node that contains information about its neighbouring nodes. This information is utilised in developing a set of rules to create a routing algorithm to forward the packets from each source to the Internet.

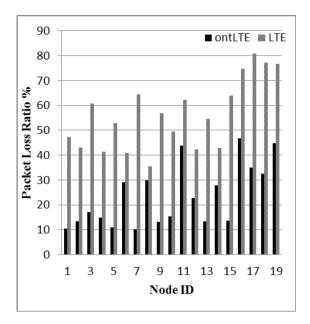Fig.7 Flowchart of creating knowledgebase instance in wireless node

Fig. 8 The packet loss ratio

The ontology is utilised in this paper to develop a set of rules to demonstrate how to employ the knowledgebase in offloading the congested LTE network using the WMN. The User Nodes start transmitting at the beginning of simulation and the sole destination is the Internet. The number of transmission nodes is 20, the traffic type is constant bit rate (CBR), packet generation rate varies between 0.5-3.5 Mbps and packet size is 500 byte. The inference engine firstly generates a list of the neighbouring Net_Node and if the load on LTE device is high the node starts to forward the traffic demand to the node with the shortest path to the MeshGw. The simulation results indicate of reducing in the number of packet loss when the ontology rules are utilised to offload LTE network load as shown in Fig. 8. Example of the rule set associated with selecting of Net_Node to offload LTE network is shown in below.

Rule: Select the Net_Node
If User_Node(ID) has_Neighbour(Net_Node) and User_Node LTE_load(high)
Then select Net_Node(shortest path).

The results in Fig. 8 shows how the LTE network (ontoLTE) reduce the percentage of error loss ratio compared to the LTE network with no offloading strategy.

Introducing ontologies enables the development of different algorithms using the same knowledge base through the use of different rules. Moreover, the uses of ontologies enable the networks to describe the data and add relationships with other services which will help in using these data in both the IoT and in big data projects.

6. Conclusion

This paper introduces a new cognitive network framework that works as an adaptor to heterogeneous transmission technology. It facilitates integration among different wireless and wired transmission technologies by creating a relationship among technology-dependent parameters and storing them in an ontology knowledge base. The proposed framework could be used to develop different services through the use of inference engine by adding new rules for reasoning using the knowledge base. Finally, a set of controls messages are designed to exchange the required information to create the knowledge base instance on each heterogeneous node. The proposed model provides the foundation for future exploration of the use of semantic technologies in representing more wireless transmission technologies such as 802.14.5 and blutooth to support nodes with limited resources and developing

smart and self-configured network application for the next generation networks. The proposed framework facilitates the process of adding new services to the network and utilising cross-layer information from the knowledge base.

Acknowledgment

References

[1]   EMC Digital Universe with Research and Analysis by IDC, "The digital universe of opportunities: rich data and the increasing value of the internet of things", 2014.
[2] 3GPP, Group service and system aspects service requirements for evolution of 3 GPP system (Rel. 8), 3GPP TS 22.278, Dec. 2008.
[3] Wi-Fi (Wireless Fidelity), IEEE 802.11 WG, IEEE 802.11-2007, Wireless LAN MAC and PHY specification, revision of IEEE 802.11 1999, IEEE LAN/MAN Standards Committee, June 2007.
[4] Iqbal M, Lim H, Wang W, Yao Y. A service-oriented model for semantics-based data management in wireless sensor networks. International Conference on Advanced Information Networking and Applications Workshops, pp. 395–400, Bradford, UK, May, 2009.
[5] Ren C, Jiang D. A new ontology of resource specification for wireless sensor networks. International Conference of Information Technology, Computer Engineering and Management Sciences, pp. 138–140, Nanjing, Jiangsu, China, September, 2011.
[6] Jabeur N, Iraqi Y, Sahli N. Semantics and routing in wireless sensor networks: Challenges and opportunities. Global Information Infrastructure Symposium, pp. 1–4, Hammamet, Tunisia, June, 2009.
[7] Kim J, Kwon H, Kim D, Kwak H, Lee S. Building a service-oriented ontology for wireless sensor networks. International Conference on Computer and Information Science, pp. 649–654, Portland, OR, USA, May, 2008.
[8] Liu L, Xiong H. Research of semantic active service mechanism for wireless sensor networks in intelligent building. International Conference Consumer Electronics, Communications and Networks (CECNet), pp. 520–524, Xianning, China, November, 2013.
[9] Luo H, Liu L, Sun Y. Semantics-based service mining method in wireless sensor Networks. International Conference on Mobile Ad-hoc and Sensor Networks (MSN), pp. 115–121, Beijing, China, December, 2011.
[10] Mittal S, Maskara SL. Towards development of wireless sensor network services based on semantic web. Annual IEEE India Conference (INDICON), pp. 1–4, Kolkata, India, December, 2010.
[11] Neto FC, Ribeiro CMFA. Dynamic change of services in wireless sensor network middleware based on semantic technologies. Sixth International Conference on Autonomic and Autonomous Systems, pp. 58–63, Cancun, Mexico, March, 2010.
[12] Xiong Q, Chen C, Wang J, Xiong W. A novel application semantics-based routing algorithm in wireless sensor networks. International Conference on Communication Systems and Network Technologies, pp. 143–146, Bhopal, India, April, 2014.
[13] Xiong Q, LI X. Cross-layer design of MAC and application semantics in wireless sensor networks. International Conference on Communication Systems and Network Technologies, pp. 147–150, Bhopal, India, April, 2014.
[14] Bispo KA, Rosa NS, Cunha PRF. A semantic solution for saving energy in wireless sensor networks. IEEE Symposium on Computers and Communications (ISCC), pp. 492–499, Cappadocia, July, 2012.
[15] IWPC International Wireless Industry Consortium, Evolutionary and disruptive visions towards ultra-high-capacity networks, pp. 1–89, 2014.
[16] Naik G. LTE WLAN interworking for Wi-Fi hotspots. In: *Proceedings of the 2nd International Conference on Communication Systems and Networks* (COMSNETS), pp. 1–2, Bangalore, India, 2010.
[17] Hagos D, Kapitza R. Study on performance-centric offload strategies for LTE networks. In: *Proceedings of IEEE 6th Joint IFIP Wireless and Mobile Networking Conference* (WMNC), pp. 1–10, Dubai, UAE, 2013.
[18] L Hu, C Colett, N Huan, IZ Kovács, B Vejlgaard, R Irmer, N Scully. Realistic indoor Wi-Fi and Femto deployment study as the offloading solution to LTE macro networks. IEEE Vehicular Technology Conference (VTC Fall), pp. 1–6, Quebec City, QC, Canada, 2012.
[19] Yang Z, Yang Q, Fu F. A novel load-balancing scheme in LTE and WiFi coexisted network for OFDMA system. In: *Proceedings of International Conference on Wireless Communications and Signal Processing*, pp. 1–55, Hangzhou, China, 2013.
[20] Chou L, Cheng S, Li C, Chen, S. Wireless network management system for WiMAX/Wi-Fi mesh networks. *Emerging Directions in Embedded and Ubiquitous Computing Lecture Notes in Computer Science*, pp. 215–225, vol. 4809, 2007.
[21] Sun W, Zhang P, Chen Y, Qin Z, Teng D. A tight coupling cooperation scheme in WiFi/WiMAX heterogeneous mesh networks. *International Journal of Computers, Communications and Control*, pp. 460–468, vol. 8, issue 3, 2013.
[22] Wang W, Liu X, Vicente J, Mohapatra P. Integration gain of heterogeneous WiFi/WiMAX networks. *IEEE Transactions on Mobile Computing*, pp. 1131–1143, vol. 10, issue 8, 2011.
[23] Hassan M., Stewart R., Brito E., and Allen J., "Deployment and Performance Issues of an Integrated Wireless Sensor Network and Wireless Mesh Campus Network", International Symposium on Communication Systems Networks and Digital Signal Processing, pp. 890 – 895, Newcastle upon Tyne, UK, July, 2010.
[24] OWL Web Ontology Language. http://www.w3.org/2001/sw/wiki/OWL, (retrieved on Feb 27, 2015).
[25] Resource Description Framework (RDF). http://www.w3.org/2001/sw/wiki/RDF, (retrieved on Feb 27, 2015).
[26] Simple Object Access Protocol (SOAP). 1.2, http://www.w3.org/TR/SOAP/ World Wide Web Consortium, May 2000.
[27] The MQTT protocol, http://www.mqtt.org, cited May, 2015.
[28] Shelby Z., Hartke K., Bormann C., and Frank B., "Constrained Application Protocol (CoAP)," Internet-Draft (work in progress), May 3, 2011. [Online]. Available: http://tools.ietf.org/html/draft-ietf-core-coap.
[29] Christian Lerche, Nico Laum, Frank Golatowski, Dirk Timmermann, "Connecting the Web with the Web of Things: Lessons Learned From Implementing a CoAP-HTTP Proxy", *IEEE 9th International Conference on Mobile Adhoc and Sensor Systems (MASS),* pp 1 – 8, Las Vegas, NV, USA, 2012.
[30] Thomas R. Gruber. A translation approach to portable ontology specifications. *Knowledge Acquisition*, vol. 5, issue 2, pp. 199–220, 1993.
[31] The ns-3 network simulator. http://www.nsnam.org/