Journal of Universal Computer Science, vol. 30, no. 2 (2024), 204-220
submitted: 21/6/2023, accepted: 9/10/2023, appeared: 28/2/2024

Mobile Handoff with 6LoWPAN Neighbour Discovery Auxiliary Communication

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Abstract: The importance of the topic under investigation stems from the burgeoning prominence of the Internet of Things (IoT) paradigm and the consequent imperative to devise and institute an efficacious methodology for neighbour detection that facilitates supplementary connections to mobile nodes. This research primarily aims to elucidate a mobile handover technique aligning with the neighbour discovery paradigm inherent in 6LoWPAN. The methodological framework employed herein amalgamates a systematic analysis of the foundational tenets governing 6LoWPAN communication standards over the IPv6 protocol in the context of IEEE 802.15.4aa personal wireless networks, supplemented with empirical evaluation of message propagation dynamics among discrete nodes of a designated personal wireless network. The findings of this investigation underscore the pre-eminence of the 6LoWPAN networking standard as a prime vehicle for bolstering the dependable communication of IoT's remote entities, contingent upon the utilization of the IPv6 communication protocol. This iteration of the Internet protocol is superior, particularly in surveillance contexts, given its expansive address capacity (128 bits) juxtaposed against its antecedent, the IPv4 protocol (32 bits). The inherent adaptability of this network connection augments the quality of mobile handover, especially when one considers the real-world application of 6LoWPAN's neighbour discovery auxiliary communication standard. The tangible implications of these findings beckon their potential utility in satiating the demands of IoT system users and actualizing the network collaboration ethos intrinsic to the 6LoWPAN communication standard.

Keywords: Internet of things, Wireless networks, Mobile node, Network protocol, Low-power personal networks, Interaction standard
Categories: C.2.3., C.2.5., H.3.5
DOI: 10.3897/jucs.108446

1 Introduction

The problem of this scientific research lies in the need to develop and implement in practice a method that involves a method for identifying 6LoWPAN neighbours for a side connection with a mobile node, where the network signal strength indicator is determined by calculating and analyzing the change in the average network signal level parameter. Today, the rapid pace of the spread of the concept of Internet of Things necessitates the introduction of efficient wireless hardware technologies and modern sensor technologies that provide a high level of service to network users [Rika et al. 2022].

The raised issues were considered in the joint scientific work of D. Wang et al. [2021], which was devoted to the study of innovative business models of the Internet energy and the construction of network enterprises. The authors note that the cost of modern power grid enterprises largely depends on the efficiency of the network connection, in which wireless communication systems are widely used today. According to scientists, shortly, the development of the concept of the Internet of Things will lead to the emergence of innovative business models and a more complete use of innovations in the field of low-power wireless personal networks [Wang et al. 2021].

In turn, a team of scientists represented by J. Gubbi et al. [2013], considered the issues of their vision of the development of architecture, elements and future directions of the Internet of Things (IoT) in a joint research work, drawing attention to the fact that the development of the technology of the Internet of things will lead to the fact that many objects around us will be in the same network format. According to researchers, this trend will lead to the creation of significant information arrays that will need to be processed, stored and presented in an acceptable format [Gubbi et al. 2013].

For their part, Q. Zhu et al. [2010] considered several problematic aspects of connecting wireless sensor networks to the Internet of Things in a joint scientific work. The authors note that to effectively perceive network security issues in the IoT environment, it is required to implement the immunity-based situation awareness (IIESSA) model. This will create a new and more effective model for perceiving security issues in the IoT environment [Zhu et al. 2019].

At the same time, a group of scientists represented by M. S. Hossen et al. [2020] concluded in a collaborative research study on the relationship between 802.15.4aa and IPv6 devices: implications and existing approaches, that current approaches to networking wireless users in the future can guarantee the interworking of multiple LoPWAN networks and provide internetworking solutions for Global Internet. Scientists note that further scientific research in this area will help ensure a high level of scientific and technological achievements and an effective solution to the identified problem.

The main goal of this research work is to evaluate the prospects for creating a technique for mobile service data transmission for an auxiliary connection with the discovery of neighbours 6LoWPAN. There is a need for an effective method for detecting neighbours for additional connection with a mobile node in IoT systems using 6LoWPAN. The current approaches do not adequately address this issue. The relationship and interworking between 802.15.4aa and IPv6 devices are not fully explored. More research is needed to ensure effective networking between LoWPAN devices and the Global Internet. Objectives are to develop and implement a technique for mobile handover for auxiliary connection with neighbour discovery 6LoWPAN. To evaluate the process of message transmission between nodes of a personal wireless network with preset parameters using 6LoWPAN. To demonstrate that the 6LoWPAN standard provides reliable IoT communication when using IPv6, due to its extended address space. To test the effectiveness of neighbour discovery for mobile handover using 6LoWPAN in practical applications. To provide results that can be applied to meet the needs of IoT system users and implement 6LoWPAN networking.

2 Literature Review

Utilizing Mobile Edge Computing (MEC) emerges as a potent solution, catering to the escalating demand for broadband services in contemporary heterogeneous systems. A salient characteristic of the forthcoming generation of radio access networks is the dense proliferation of small cell networks, meticulously designed to augment requisite capacity. However, it is imperative to address the challenges of sustainable networking and service computation, particularly in the downlink. This is because an indiscriminate deployment of an excessive number of small cells could inadvertently escalate operational expenditures and augment carbon dioxide emissions. [Xu et al. 2021] Moreover, considering the constraints in terms of resources and computational capacities at the user layer, ensuring energy efficiency (EE) and upholding fairness become paramount in MEC-integrated cellular frameworks [Mohajer et al. 2022a]. In the realm of small-cell network design, there is a prominent trend to utilize high-capacity backhaul links operating on millimetre-wave bands. The primary objective of this approach is to establish multi-hop topologies, thereby alleviating data transmission overheads. Quantitative analysis reveals that by integrating power optimization with a hybrid backhaul architecture, there is a potential to augment the overall network throughput by 18% in comparison to prevailing optimized static architectures. Concurrently, this methodology exhibits a decrement in energy consumption by approximately 30%. Furthermore, a notable enhancement in user quality satisfaction, gauged at 24.5%, was observed in user distribution patterns [Dong et al. 2023].

In the realm of next-generation mobile networks, the dense deployment of small-cell infrastructures stands out as a distinguishing characteristic geared towards facilitating an augmented capacity. These small cells, strategically placed within territories demarcated by macro base stations (eNBs), endeavour to cater to localized capacity needs, echoing the established paradigm of hierarchical HetNets [Shynkariuk 2022]. Furthermore, small-cell networks capitalize on high-capacity backhaul connections in the millimeter-wave spectrum to contrive multi-hop topologies, a strategic move to curtail data transmission expenditures. However, the principle of green networking ascends in prominence, as unchecked proliferation of small cells can inadvertently inflate operational expenses and exacerbate carbon dioxide emissions [Stepanchuk et al. 2016]. Quantitative analyses manifest a notable reduction in power consumption across various traffic models, all the while upholding throughput benchmarks for both uniform and hotspot distributions of user equipment [Mohajer et al. 2022b].

Mobile handoff is a crucial aspect of wireless communication systems, which allows mobile devices to maintain connectivity while moving between different networks. The article "Mobile Handoff with 6LoWPAN Neighbour Discovery Auxiliary Communication" [Tongrang et al. 2019] proposes an extended 6LoWPAN neighbour discovery protocol to improve the discovery mechanism in 6LoWPAN and reduce handoff latency. Leveraging the mobility support inherent in IPv6 coupled with its node discovery mechanism, this study introduces an innovative approach that utilizes the node discovery mechanism to facilitate auxiliary connections for mobile nodes. The methodology entails monitoring the real-time Received Signal Strength Indicator (RSSI) and, through computational analysis, determining the average value fluctuations to anticipate its variation trend. Empirical results indicate that this method is particularly apt for the stub networks within the Internet of Things (IoT) in familiar dynamic environments [Novitasari et al. 2022]. Furthermore, when benchmarked against the conventional 6LoWPAN, it manifests enhanced efficiency and a significantly reduced packet loss probability.

Research scientists J. Ko and A. Terzis [2011] note in a joint scientific study of the general principles of connecting low-power and lossy networks to the Internet, that wireless networking research conducted in the past decade showed that the network architecture of the Internet was not suitable for those used on that moment of network applications. The authors draw attention to the fact that the 6LoWPAN and RoLL WG protocols determine the effectiveness of IPv6 adaptation mechanisms for 802.15.4aa links, as well as IPv6 packet encapsulation and autoconfiguration functions, including routing protocols for a device with limited resources.

Several studies have been conducted to improve the performance of mobile handoff in wireless communication systems. A survey of handoff performance in Mobile IP was conducted by G. Chellani and A. Kalla [2013], which analyzed the performance of Mobile IP in different scenarios. The study found that Mobile IP suffers from long handoff latency and packet loss, which can affect the quality of service. Hung et al. [2008] proposed a method to improve handover performance in Mobile IPv6 by reducing the handover latency. The proposed method uses a fast handover mechanism to reduce the handover latency and improve the performance of Mobile IPv6. Boukerche et al. [2017] conducted research on handover in Mobile IP and proposed a method to reduce the handover latency by using a predictive handover mechanism. The proposed method uses a prediction algorithm to predict the next access point and initiate the handover process in advance [Jain et al. 2022]. The article "An Initial Approach to Support Mobility in Hospital Wireless Sensor Networks based on 6LoWPAN (HWSN6)" [Jara et al. 2010] proposed a method to support mobility in 6LoWPAN by using a neighbour discovery mechanism. The proposed method reduces the handoff latency and improves the performance of 6LoWPAN.

In conclusion, mobile handoff is a crucial aspect of wireless communication systems, and several studies have been conducted to improve its performance. 6LoWPAN is a low-power wireless communication protocol designed for IoT devices, and several studies have been conducted to improve its performance.

3 Materials and Methods

The methodological approach in this scientific study is based on a combination of methods of system analysis of the general principles of using the LoWPAN 6 interaction standard over the IPv6 protocol on personal wireless networks of the IEEE

802.15.4aa standard, with an experimental study of the data transfer process between two nodes of a personal wireless network with specific typical parameters. In addition, the method of analytical comparison of the results obtained in this scientific study with the results and conclusions of several scientific studies aimed at studying the problems of data transmission over a mobile network, as well as related to them, was used. In this scientific study, the Contiki system was used, which performs the function of maintaining the required mobility parameters of network nodes. Also, to conduct a scientific experiment, the Cooja stimulator was used, which is designed to clarify experimental data. As part of the scientific research, a theoretical base was prepared, which included an analysis of the results and conclusions of the work on some topics related to the chosen scientific direction.

The application of the method of system analysis of the principles of using the 6LoWPAN interaction standard over the IPv6 protocol made it possible to determine the key principles of neighbour detection in wireless networks with low power consumption and limited range. In addition to it, the role of the functional group of the 6LoWPAN interoperability standard was formulated, which standardized the IPv6 Internet protocol with an emphasis on ensuring the efficiency of transmitting datagrams of this protocol in the 802.15.4aa standard mode and maintaining IPv6 compatibility targets for the discovery function in a network with wide range domains.

An experimental study of the sequence of data transmission between specific nodes of a personal wireless network made it possible to test sending a message in the real communication space of the network. During the pilot study, the Contiki system, as well as the Cooja stimulator, were used to create a model of a given network space and refine the results.

The chosen combination of scientific research methods determined the presence of its following stages.

At the first stage of this research work, the theoretical aspects of using the IPv6 version of the Internet protocol in the 6LoWPAN interoperability standard were considered. A theoretical evaluation of the Internet protocol IPv6 on 6LoWPAN was given, in the context of providing mobile data transmission in the neighbourdiscovery auxiliary communication network.

At the next stage of this scientific research, an experimental study was carried out, during which the testing of the efficiency of data transmission between individual nodes of the wireless network was carried out. The experiment was carried out using the capabilities of the Contiki system and the Cooja stimulator, which made it possible to form a model of the network space and refine the obtained results. The results of the experiment are presented in the corresponding graphical representations.

At the final stage of this research work, an analytical comparison of the results obtained during it with the results of several studies aimed at studying the complex problematic aspects of building personal wireless networks and related to them was carried out. This made it possible to clarify the results obtained in this scientific study and form conclusions based on them, acting as their logical reflection and summing up the entire complex of research operations performed.

4 Results

4.1 Semantic based Retrieval using Meta data

Internet protocol version IPv6 is the best option for fixing and monitoring applications. The length of the address is significantly extended compared to the IPv4 version and is 128 bits (32 bits for IPv4). Moreover, integration with the architecture of the Internet provides flexible connectivity, and optimal innovation solutions are present in each layer of the stack (Ko and Terzis, 2011).

For this reason, the Internet Engineering Task Force (IETF) established the 6LoWPAN working group in 2005 to standardize the use of IPv6 over the IEEE 802.15.4aa standard (IEEE 802.15.4aa, 2003), whose key parameters are fundamentally different from previous communication technologies such as Ethernet or Wi-Fi. To address this issue, the 6LoWPAN functional group focused on the following key aspects:

- how to ensure the efficient transmission of IPv6 datagrams within the 802.15.4aa standard.;
- how to guarantee the required IPv6 compatibility parameters of the discovery function in a network with broad spectrum domains [Ko and Terzis 2011].

Such a mobile node management technique can be successfully implemented, but it should be noted that it has some technical difficulties. The problems stem from the large scale and complexity of the control system, and improvements are needed as numerous mobile nodes increase network load, and low overall network power consumption makes individual node power consumption significant [Sinaj et al. 2023].

Most IoT technologies, such as Low Power Wide Area Networks (LPWANs), are non-IP due to the difficulties of using IP on constrained devices. These nodes are characterized by more constraints concerning other IoT technologies. The key to solving the issue of using IP on constrained devices is the header compression mechanisms [Ayoub et al. 2019]. There are two IETF standardized solutions, SCHC and 6LoWPAN, to compress IPv6 over constrained nodes within LPWAN. SCHC protocol solution as an adaptation layer between the network layer and the link layer is better in terms of header compression by providing a smaller header size compared to 6LoWPAN. Consensus is a basic building block in distributed systems for a myriad of related problems that involve agreement. Failure Detectors (FDs) have since emerged as a possible remedy, able to solve consensus in asynchronous systems under certain assumptions. With the increasing use of asynchronous, wireless Internet of Things (IoT) technologies, such as IEEE 802.15.4/6LoWPAN, the demand for applications that require some form of reliability and agreement is on the rise. What was missing so far was an FD that could operate under the tight constraints offered by Low Power and Lossy Networks (LLNs) without compromising the efficiency of the network [Raich and Kastner, 2022].

To implement the 6LoWPAN standard in wireless sensor networks, the working group overcame several practical difficulties. Although IPv6 provides some level of mobility, mobility in wireless sensing networks is an unresolved issue.

An evaluation of the IPv6 internet protocol on 6LoWPAN was given in a study [Dunkels et al. 2020]. The capabilities of the lightweight operating system Contiki built around the core, which manages processes on the network, are noted. At the same time, dynamic loading and unloading of the wireless sensor network become possible only in environments with limited resource consumption. Contiki requires only several K Bytes of code and a few hundred bytes of memory to provide a multitasking environment and built-in TCP/IP support, making it especially suitable for memory-constrained embedded platforms [Marino et al. 2022]. Contiki has been used to design and implement a lightweight 6LoWPAN gateway that can realize the interconnection between 6LoWPAN networks and the Internet. Contiki has also been used to implement the proposed SD-6LoWPAN architecture, which enables software-defined networking in 6LoWPANs. Furthermore, Contiki has been used to implement an Elliptical Curve Cryptography-based Diffie-Hellman key exchange mechanism for Internet of Things devices. Successful implementation of 6LoWPAN/CD on bare metal CC430-based sensor nodes has been designed and implemented using Contiki [Honggang et al. 2018]. Overall, Contiki's benefits for implementing the 6LoWPAN standard include its portability, multitasking environment, built-in TCP/IP support, and suitability for memory-constrained embedded platforms.

When using the 6LoWPAN interworking standard, the neighbour identification sequence is reflected in the RPL protocol. The creation of the protocol was intended to satisfy the requirements set out in [RFC5867], [RFC5826], [RFC5673] and also in [RFC5548]. Several RPL samples are allowed to work simultaneously on the network [Thubert et al. 2012].

4.2 Auxiliary 6LoWPAN Neighbour Discovery Principle

The 6LoWPAN interworking standard is characterized by low power consumption and short-range transmission parameters, which makes it suitable for use in a wireless mobile network in which data is transmitted over a short distance. This is necessary to create devices connected to a network, as well as to manage Internet access using the IPv6 protocol. 6LoWPAN nodes use IPv6 access to the Internet, which determines the equality of Internet of Things (IoT) nodes and the Internet (Asghari et al., 2019). The density of 6LoWPAN is somewhat higher than that of other wireless networks of this topology since the communication coverage area is larger. Messages on the network are transmitted in several stages, ensuring their delivery to 6LoWPAN [Tongrang et al. 2019].

The neighbour discovery technique is a key component of the IPv6 protocol. Its main functions include routing and prefix detection, address resolution, access confirmation, and redirection [see Fig. 1].

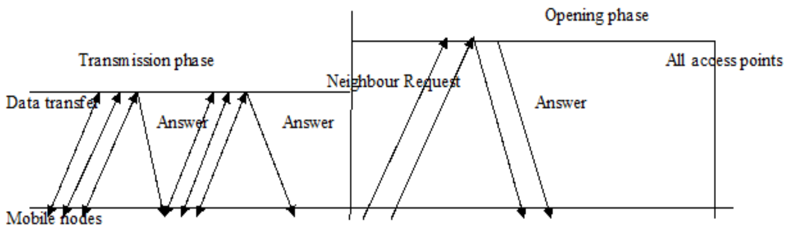


Figure 1: Mobile Switching Process
Source: Tongrang et al. [2019].

RPL protocol provides for the use of the root node as a node providing access to the mobile network or a network router. This automatically creates a table of neighbours and maintains a routing table. Opening the RPL protocol only requires placing a node as the root, followed by placing a directed acyclic graph topology that is oriented towards the final destination [Tongrang et al. 2019].

4.3 Experiment

To clarify the information and obtain more accurate data, an experiment, which consisted of sending a test message in a real communication space, was conducted. After that, using the simulator, a model of a switching network of a given scale was created. During the experiment, the Contiki system, designed to maintain the necessary parameters for the mobility of nodes, was used. The obtained data is refined by creating a model in the Cooja simulator.

The node movement tracking configuration is shown in Figure 2.

In the first column of this figure, the serial number is indicated, in the second column, the final travel time is indicated. The next two columns present the coordinates of the nodes along the abscissa and ordinate axes.

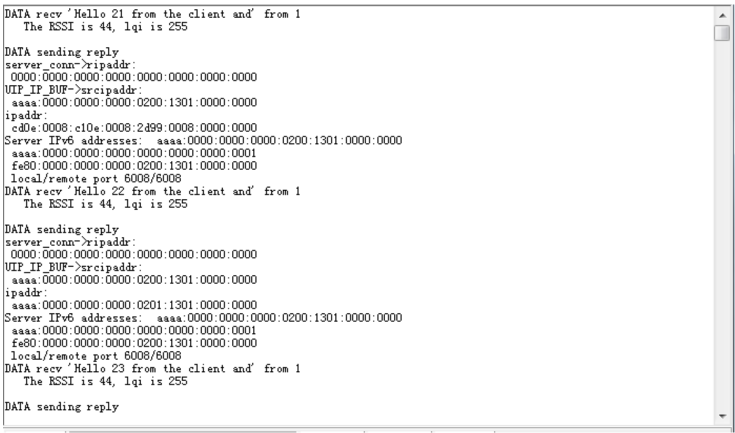
After the experiment, carried out in real conditions, to clarify the obtained data, a test is carried out in the Cooja simulator. Through the use of the Contiki application, the state of the connecting nodes of the network was monitored. Data was transferred through a local port to a remote computer [see Fig. 3].

```
# Model used: Random Waypoint model
#Number of nodes 15
#Time [s]: 600.0 seconds
#Min speed [m/s]: 1.0
#Min speed [m/s]: 4.0
#Min pause time [s]: 2.0
#Min pause time [s]: 10.0
#Currently disregarding the first 10 seconds
#Resolution []: 0.2
#Maximum X-Size [m]: 130.0
#Maximum X-Size [m]: 130.0
#Note that nodes index here start at zero due to Cooja input format
#However, the modes are indexed ≥ 1 in stat file
#
#==================================
0.0.0.44.0413538236 135.737294054
1.0.0.39.1822871509 109.741972953
2.0.0.117.418994575 123.906576338
3.0.0.78.382316355 87.7137366549
4.0.0.57.9317800626 22.5728190372
5.0.0.117.055992576 75.9665997419
6.0.0.75.3371569251 21.6535691046
7.0.0.9.04349427752 47.9286501914
8.0.0.56.7195658553 75.4141633105
9.0.0.86.0087077031 112.983944104
10.0.0.41.9024464493 74.4717375123
```

Figure 2: Node movement tracking configuration
Source: Tongrang et al. [2019].

The RPL protocol provides additional features for the transmission of information over networks with a dynamically formed topology. This allows saving the minimum configuration of nodes, which gives the possibility of their autonomous operation [Thubert et al. 2012]. In the individual applications used, the RPL takes into account the topologies of routers that are assigned independent prefixes. Their aggregation may or may not be used depending on the type of routing devices.

6LoWPAN addressing has quite definite differences from typical IPv6 addressing. In practice, there is compression of IPv6 addresses to solve 6LoWPAN problems. The operation of the 6LoWPAN interaction standard is carried out on the principle of a flat address space, which implies the presence of only one auxiliary network of the IPv6 protocol within the wireless network. In the internal space of the auxiliary network, there are unique media access control addresses. The final length of these addresses is 64 or 16 bits. Thus, IPv6 address compression can be implemented by omitting the IPv prefix, IID (interface identifier) compression and multicast address compression [Devasena 2019].



```
DATA recv 'Hello 21 from the client and' from 1
   The RSSI is 44, lqi is 255

DATA sending reply
server_conn->ripaddr:
 0000:0000:0000:0000:0000:0000:0000:0000
UIP_IP_BUF->srcipaddr:
 aaaa:0000:0000:0000:0200:1301:0000:0000
ipaddr:
 cd0e:0008:c10e:0008:2d99:0008:0000:0000
Server IPv6 addresses:  aaaa:0000:0000:0000:0200:1301:0000:0000
 aaaa:0000:0000:0000:0000:0000:0000:0001
 fe80:0000:0000:0000:0200:1301:0000:0000
 local/remote port 6008/6008
DATA recv 'Hello 22 from the client and' from 1
   The RSSI is 44, lqi is 255

DATA sending reply
server_conn->ripaddr:
 0000:0000:0000:0000:0000:0000:0000:0000
UIP_IP_BUF->srcipaddr:
 aaaa:0000:0000:0000:0200:1301:0000:0000
ipaddr:
 aaaa:0000:0000:0000:0201:1301:0000:0000
Server IPv6 addresses:  aaaa:0000:0000:0000:0200:1301:0000:0000
 aaaa:0000:0000:0000:0000:0000:0000:0001
 fe80:0000:0000:0000:0200:1301:0000:0000
 local/remote port 6008/6008
DATA recv 'Hello 23 from the client and' from 1
   The RSSI is 44, lqi is 255

DATA sending reply
```

Figure 3: Link State Test Data
Source: Tongrang et al. [2019].

The presence in the conditions of modern large cities of increased demand for a large space of IP addresses causes the widespread use of the IPv6 protocol (128 bits). This type of 6LoWPAN interoperability network includes many low-power devices equipped with touch sensors for use in smart city systems where wireless data transmission is required under low-power consumption conditions. This contributes to an increase in demand for new applications in wireless sensor networks, which are typically characterized by low power parameters, and relatively low cost. Such networks are distributed and self-organizing, the connection is made directly to the Internet using the IPv6 protocol [Tamariz-Flores et al. 2020]. It is advisable to use them in smart cities, and smart homes, as well as in other technological devices that do not require the use of resources in significant volumes and in real-time. For this purpose, warehouse services can be specially allocated.

Figure 4 shows a block diagram of the 6LoWPAN architecture. The main key elements that determine the effectiveness of the functioning of this standard of interaction via the IPv6 protocol over low-power wireless personal networks are noted. Such an architecture is typical for applications designed to automate the processes of managing production, stationary or office space. The ability to connect such networks to the Internet opens up additional possibilities for managing them.

The presence of the block diagram shown in Figure 4, ad-hoc nodes LoWPAN virtually means that this network is not connected to the Internet. Simple LoWPAN involves embedding several nodes at once into one common LoWPAN, with one border router. It provides connectivity to multiple network internet routers. The next in line is the extended LoWPAN, in which several network routers operate. They are connected to the main link, which provides additional opportunities for connecting to the Internet. Thus, the use of additional network routers guarantees an increase in the amount of payload in the network. At the same time, 6LoWPAN can minimize the header or compress it, while the payload increases by more than 110 bytes. This means actual header compression [Devasena, 2019].

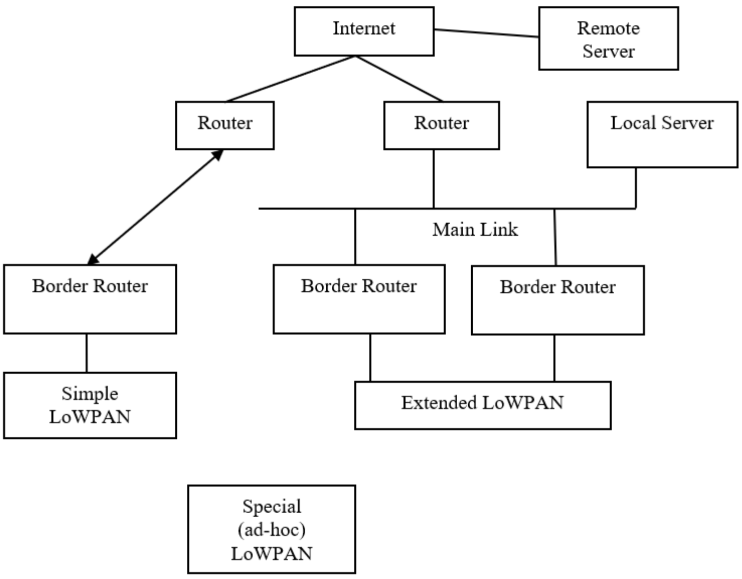


Figure 4: 6LoWPAN architecture
Source: C. L. Devasena [2019].

The typical 6LoWPAN RPL Routing Protocol Architecture in limited-range devices uses the concept of a directed acyclic graph in terms of loop-free design, multipath, fast and relatively simple configuration, self-refreshing capability, and minimal network delays. The energy efficiency of the application of this protocol gives reason to consider this aspect as one of the weakest aspects of this routing protocol. This negatively affects the entire network as a whole, has a bad effect on reliability, and reduces the overall operating time. In addition, RPL is predominantly focused on the distribution in large volumes of both heterogeneous and homogeneous devices of low power. This causes irregularities in data transfer on the root node, which causes unnecessary problems with power consumption and finding the optimal load balance [Gidado 2022].

The Internet of Things (IoT) in a personal wireless network according to the 6LoWPAN interoperability standard has recently attracted attention because it provides seamless connection of various nodes and objects in many areas [Dhanvijay and Patil 2019]. The current state of the topology of the network architecture gives grounds for continuing scientific research in the field of mobile handover with 6LoWPAN Neighbour Discovery Auxiliary Communication. This will transform many areas of everyday life, gradually and completely rebuilding applications, technical devices and people who interact with them towards improvement [Aviv et al. 2023].

The main motivation of the proposed method is to solve the mobile switching problem in 6LoWPAN networks for the Internet of Things (IoT). Existing mobile switching methods in 6LoWPAN face the problems of high delay and packet loss during switching, which degrades the quality of service. This is due to the limited resources of 6LoWPAN nodes and the difficulty of integrating standard mobility mechanisms, such as Mobile IP, into these networks.

The proposed method solves this problem by using an extended neighbour discovery protocol 6LoWPAN, which uses auxiliary communication for mobile nodes. This reduces delay and handover loss, as the mobile node can quickly establish a connection with a new receiver before the current connection is broken.

Advantages of the proposed approach:

1) Reduced latency and packet loss during switching compared to standard methods.

2) Improving the quality of service for mobile applications in 6LoWPAN.

3) Compatibility with limited resources of 6LoWPAN nodes.

4) Using native IPv6 mobility support.

5) Ease of implementation compared to the adaptation of complex mobility protocols.

Therefore, the proposed approach effectively solves the mobility problem in 6LoWPAN for IoT, ensuring low latency, minimal data loss, and high quality of service.

Utilizing mobile handoff techniques in tandem with the 6LoWPAN neighbour discovery auxiliary communication protocol offers the potential for real-time surveillance of machinery and equipment functionality. Such continuous monitoring facilitates the early detection of malfunctions, preempting substantial operational issues. In industrial contexts, this protocol can be employed to supervise environmental parameters including temperature, humidity, and air quality—integral metrics for ensuring occupational safety and health standards. Within residential networks, the integration of mobile handoff with 6LoWPAN neighbour discovery auxiliary communication enables the interconnection of various IoT devices. This includes, but is not limited to, smart thermostats, surveillance systems, and adaptive lighting mechanisms, all of which can be remotely regulated via digital devices like smartphones or tablets [Shulga 2023]. Moreover, this system offers a strategic vantage point to oversee household energy consumption, subsequently aiding in the optimization of energy expenditure and the promotion of sustainable practices. In educational and training paradigms, particularly within medical pedagogy, this technology can be harnessed for the creation of experimental simulations. Trainees can deploy sensors to mimic real-world clinical scenarios, receiving instantaneous feedback. Additionally, in the realm of athletic training, the protocol can be exploited to analyze athletes' performance metrics, thereby offering insights into their technique refinement.

5 Discussion

The research team represented by A. Dunkels et al. [2020] draws attention to the fact that building large networks of wireless sensors implies the possibility of downloading code to the network in the work devoted to the study of the principles of building operating systems for tiny network sensors of local computer networks. Sensory wireless networks include a variety of small-sized sensory devices that provide wireless communication capabilities. According to the scientists, the Contiki system they developed can be effectively used to provide sensor network hardware multiplexing between different applications or even a certain number of users [Dunkels et al. 2020]. The conclusions of the researchers fundamentally coincide with the results obtained in this scientific work, significantly expanding them in the context of assessing the prospects for the practical application of the Contiki system.

For their part, M. Grajzer and M. Glabowski [2014], in a joint scientific study of the principles of setting up experiments with IPv6 in wireless mobile networks of low ranks, concluded that the need and importance of rigorous testing of wireless sensor networks increases as the demand for an uncontrolled Internet network based on IPv6 increases. According to the authors, while network simulators are powerful tools that enable the simulation of IPv6-based MANET solutions in many diverse environments, several modelling limitations can be effectively addressed through the implementation of emulators and test benches [Grajzer and Glabowski 2014]. The conclusions of the researchers do not fundamentally contradict the results of this scientific work, while they require practical verification in real conditions.

At the same time, a team of researchers represented by F. Tongrang et al. [2019] considered in a joint scientific work the installation of auxiliary communication for the detection of mobile nodes 6LoWPAN. Scientists note that the Internet of Things, which is currently in the stage of intensive development, is effectively integrated with IPv6, artificial intelligence systems, sensors, cloud computing, smart devices and several other technological solutions and is used in areas closely related to human activity. The scientists concluded that with the next-generation network and low-power network technology promoting and constantly popularizing, the 6LoWPAN protocol has gradually supplanted ZigBee, now it is a node interconnection (IoT) and interoperability capability through IPv6 [Tongrang et al. 2019]. The results obtained by scientists correspond to the results of this scientific work, significantly expanding them.

The topic is being developed by a group of scientists represented by H. Zhang et al. (2016) in a collaborative paper on how to deal with legacy mappings driven by mobility in networks with distributed identifiers and locators. According to researchers, in wireless networks, the routing is differentiated from routing in provider networks, as a rule, the tunnel arrangement of packets from the ingress tunnel router (ITR) to the egress tunnel router (ETR) is used [Zhang et al. 2016]. The researchers formulate the conclusion that in the case of a deliberate separation of the router and the locator, the input tunnel router caches some identifiers that were previously used in the locators to display several remote wireless network nodes. The conclusions of scientists are controversial since they require verification in various practical conditions.

For their part, H. Xie et al. [2021] who jointly reviewed the performance parameters of the RPL routing protocol in 6LoWPAN, concluded that the RPL routing protocol can be qualitatively adapted to changes in the typological scheme of a wireless network, and the performance parameters of this protocol are significantly superior to other types of routing protocols in 6LoWPAN. It is also noted that this protocol is characterized by higher stability than protocols of the AODV, and DYMO types [Xie et al. 2021]. The results obtained by the researchers fundamentally coincide with the results of this scientific work, in the context of comparing the effectiveness of the 6LoWPAN routing protocol with the capabilities of other protocols, significantly expanding them in terms of comparison with specific examples.

This topic was developed in a scientific study by E. I. Tamariz-Flores et al. [2020] aimed at studying the features of indoor temperature monitoring based on the capabilities of the 6LoWPAN network. According to a group of researchers, the range of practical use of wireless sensor networks (WSN) in various areas of public life is gradually expanding, which requires the search for new opportunities for information exchange. The authors also note that 6LoWPAN is a kind of hybrid type network that connects to the Internet through the use of devices that have very limited resources and require the use of IPv6 [Tamariz-Flores et al. 2020]. Scientists express the opinion that it is for this reason that 6LoWPAN plays a key role in the implementation of wireless sensor network complexes. The opinion of scientists does not fundamentally contradict the results, obtained in this scientific work, while in the context of these results it seems incomplete.

A group of scientists consisting of M. S. Pedro et al. [2013]. Skarmeta conducted a collaborative research study on PANA-based network access control implementation options for Internet of Things (IoT) devices. The researchers note that today the Internet of Things (IoT) networks represent a qualitative basis for the development of several technological scenarios, such as smart cities, as well as applications of various systems. According to the authors, today it has become absolutely real to expand the range of applications of small-sized technological devices that have wide capabilities and operate based on the use of the Internet protocol (IP) [Pedro et al., 2013]. As a rule, they form wireless networks of transmitting nodes that can independently recover from communication failures. The conclusions of the researchers fundamentally coincide in key aspects with the results obtained in this scientific work.

C. L. Devasena [2019], in a scientific study of methods for building a low-power IPv6 wireless personal area network (6LoWPAN) for the Internet of Things (IoT), concluded that the architecture and specific details and elements of the 6LoWPAN protocol demonstrate its full suitability for use for the Internet of things. According to the scientist, the common link layer 6LoWPAN allows maintaining the presence of some small-sized elements in the network. All the key features of IPv6 are present, while there is the possibility of a qualitative improvement in the system of interaction with small nodes. All this makes the 6LoWPAN protocol quite acceptable for the Internet of Things [Devasena, 2019]. The conclusions of the researcher are in full accordance with the results of this scientific work.

In turn, R. Gard and S. Sharma [2017], in a joint scientific study of the need for an adaptation layer in the 6LoWPAN protocol stack, concluded that this protocol stack appeared to ensure high efficiency in the transmission of IPv6 packets over a low power wireless personal area network. At the same time, it is noted that an improvement in the adaptive characteristics of the levels of data transmission links of the TCP/IP stack and network should be considered a significant change [Gard and Sharma, 2017]. The conclusions of scientists fundamentally coincide with the results obtained in this scientific work.

Thus, the discussion of the results obtained in this scientific study, in the context of their comparison with the results of several research works on similar topics, demonstrated their fundamental coincidence in some key aspects. This is evidence of the scientific validity of the results of this scientific work and the expediency of their practical application in the development of a mobile handover model with 6LoWPAN neighbour discovery auxiliary communication.

6 Conclusions

Drawing on the evident trajectory of progressive enhancement and an expanding acceptance among network aficionados, later adaptations of low-power network technologies with distinct domains have systematically superseded 6LoWPAN's antecedent, ZigBee. Presently, 6LoWPAN stands as the paragon for the integration of IoT nodes through the IPv6 connection protocol. Given the intrinsic short-range attributes of the 6LoWPAN standard under scrutiny and its minimal energy consumption requirements, it frequently emerges as the preferred networking solution for mobile points within the Internet of Things (IoT) framework. Nonetheless, such nodes encounter inherent challenges in orchestrating mobile devices, a predominant issue when directly addressing IoT terminal performance.

Delving deeper into 6LoWPAN neighbour discovery and pioneering alternate communication linkage strategies could potentially unravel innovative methodologies for orchestrating node movements and refining user accessibility within a constrained IoT spectrum. The feasibility of such innovations is corroborated by findings from this academic inquiry. Furthermore, the rationale for IPv6 compatibility is fortified, advocating its integration with wireless sensor networks and the broader Internet. Given its extant pertinence, 6LoWPAN remains a focal point in research circles, especially concerning its potential enhancements that could amplify network performance metrics. This augments its applicability, spanning sectors such as industrial and social infrastructure monitoring, intelligent housing systems, experiential learning, and beyond.

In light of the above, it is imperative to perpetuate inquiries surrounding mobile handover mechanisms interwoven with 6LoWPAN neighbour discovery auxiliary communication. Successive scholarly endeavours in this domain will invariably bolster advancements in the Internet of Things (IoT), low-energy wireless sensor networks, and an array of emergent technological innovations.

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