An Intelligent Elevator System Based on Low Power Wireless Networks

Congying Yu, Ruize Sun, Qijun Hong, Weiwen Chao, and Lei Ning(✉)

College of Big Data and Internet, Shenzhen Technology University, Shenzhen, China
`ninglei@sztu.edu.cn`

Abstract. The trend of Internet of Things (IoT) and wireless network techniques have resulted in a promising paradigm, and a more rational and intelligent elevator control system shall be considered. Many previous works are devoted to improving traffic congestion capability to increase time efficiency. However, these approaches confront the limitations of destination perception in advance or there is a steady stream of persons coming to wait the elevator that may increase the uncertainty of sensing the traffic load, since the user interface is still around elevator car. In this paper, an improved elevator system is proposed with remote calling and cloud scheduling based on low power wireless networks. It enables users to call the elevator remotely through portable devices, solves the problem of elevator invalid stop, reduces system energy consumption, and improves the service life of the elevator. It can match the running state of the elevator with the multi-user call request, shorten the time for users to take the elevator, and improve the comprehensive operation efficiency of the elevator.

Keywords: Elevator scheduling · Low-power wide-area network · Narrow Band Internet of Things · Elevator networking

1 Introduction

With the development of the information society, the connection objects of the network gradually expand from the connection between persons to the connection among people and things [1]. At the same time, the number of node connections in the network will also exceed 100 billion scale, and the information society has also moved from the Internet at the beginning of its birth to the era of IoT, which extends the way of network connection and data exchange, from consumer wearable devices to industrial production devices [3,5,14,17]. These terminals can sense environmental information, be controlled remotely, make decisions and take actions. Therefore, IoT technology plays an important role in the development of intelligent information society towards a higher level.

Sponsored by the Young Innovative Project from Guangdong Province of China (No. 2018KQNCX403) and the Teaching Reform Project from Shenzhen Technology University (No. 2018105101002).

X. Wang et al. (Eds.): 6GN 2020, LNICST 337, pp. 253–262, 2020.
https://doi.org/10.1007/978-3-030-63941-9_19

The expected explosive growth of IoT nodes depends on the evolving wireless communication technology, network infrastructure scale, terminal chip equipment and data and computing center. In recent years, in order to better support the network access of IoT nodes and meet the needs of IoT comprehensive application, IoT wireless access technology also presents the development trend of a hundred flowers and a hundred schools of thought. For example, in the field of authorized spectrum, based on the fourth generation cellular mobile communication (4G) technology, the enhanced Machine Type Communications (eMTC) supporting voice communication and Narrow Band Internet of things (NB-IoT) with low-power access technology and tiny packet data reporting service are developed [11,19]. In the field of unauthorized spectrum, the wireless access technologies such as WiFi, Bluetooth, ZigBee and Lora have also been widely deployed to meet the business requirements of different individuals and enterprises for node power consumption, coverage distance and transmission rate. However, because the Cellular Internet of things (CIoT) uses the authorized spectrum and is deployed by the operators on a large scale, it has better anti-interference and wide area coverage continuity, which can save the deployment cost of the user network, reduce the node access cost and guarantee the Quality of Service (QoS) [21].

Therefore, the trend of IoT and wireless network techniques have resulted in a promising paradigm, and a more rational and intelligent elevator control system could be considered [6,12,15]. By the end of 2016, there were more than 15 million elevators running in various buildings around the world, with billions of people taking elevators every day. Huawei expects 70% of the world's population to live in cities by 2050. In the next 20 years, there will be about 3 billion people entering the city [2,6,7,16]. After so many people enter the city, the limited space of the city will certainly promote the construction of high buildings, and the elevator will become more and more important. At present, China is probably the largest country in the world to carry out urbanization. At the beginning of 2015, a third-party report showed that in 2014, the proportion of new elevators in the global market in China was more than 68%, which means 68 of the new 100 elevators were installed in China. Obviously, it is necessary to deploy multi car elevator system with an intelligent scheduling to improve the transportation efficiency of large buildings with hyper dense people. However, due to the instantaneous increase of traffic load and the limitation of elevator car capacity, the elevator system is still faced with serious traffic congestion bottleneck in peak hours [5,14].

A lot of previous works are devoted to improve traffic congestion capability to increase time efficiency. In [4,9,20], it is an optimization of elevator scheduling that focuses on the stand-alone central controller for peak hours, while lacking the solution of sensing the external environment of elevator. In [10,18], multi-functional sensors were equipped at the floors for mainly detecting the passenger inside and outside the elevator car. However, these approaches confront the limitations of destination perception in advance. Therefore, proactively computing on the fine-grained traffic load information by the elevator system from each floor was proposed in [6,8]. This smart elevator system is to integrate traffic load by dynamically managing user interface and providing intelligent suggestions to guide passengers ride to other adjacent floors for time saving and physical health consideration. However, there is a steady stream of persons coming to wait the elevator that may increase the uncertainty of sensing the traffic load, since the user interface is still around elevator car.

In this paper, an improved elevator system is proposed with remote calling and cloud scheduling based on low power wireless networks. This work adopts remote call by the general portable equipment, which not only reduces the management cost, but also solves the problem of inaccurate identification of the number of incoming persons. The elevator dispatching center in the cloud receives the call data of users and the running state of the elevator at the same time, and judges the full load through multi factors. The design reduces the number of ineffective elevator door opening and closing, while improving the running efficiency of the elevator. The user call data and elevator data are presented on the web through the visual interface, which can give the maintenance personnel a more comprehensive and intuitive elevator operation health state, making the elevator maintenance become more active, rather than passive maintenance after failure or accident.

2 System Model

The novel elevator system is based on the layered concept of IoT including the perceptual recognition layer, network construction layer, cloud computing layer and application layer, which stands for smart elevators, the floor identification and related information transmission, the elevator scheduling center and the user interface, respectively.

In the layered concept of IoT, the perceptual recognition layer is a link between the physical world and the information world, so the smart elevators can report the running status and receive the instructions via wireless networks from the cloud. The network construction layer is a pipeline to exchange the information between the physical elevator and the remote control system. Meantime, with the support of high-performance computing and mass storage technology, the cloud computing layer organizes large-scale data efficiently and reliably, and provides intelligent scheduling for elevator applications.

The application layer is an integrated service provider and instructions collector. Thus, the unified interface of human-computer interaction is adopted in this paper, which is a cross platform architecture ranging from the web browser to the mobile mini program.

3 Design of Intelligent Elevator System

As it is shown in Fig. 2, users utilize the portable devices to detect the corresponding wireless identification signals of their particular floors, and send the messages including the present floor information, call requests and target

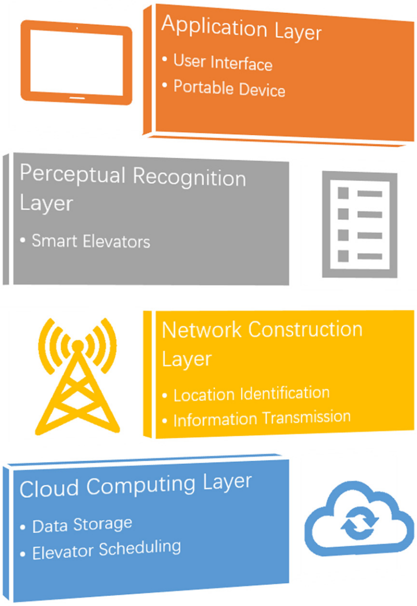

Fig. 1. The novel elevator system architecture based on the layered concept of IoT.

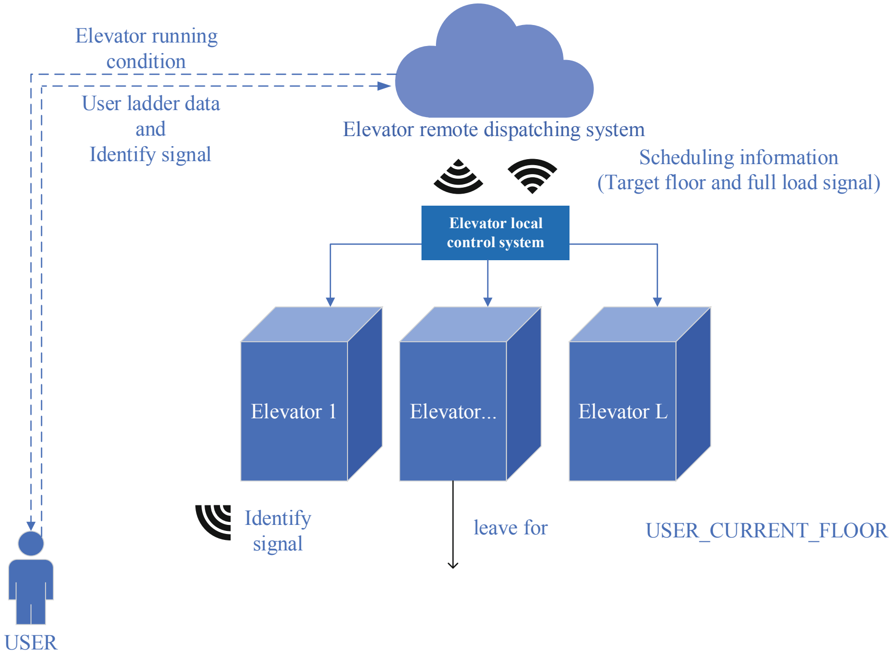

Fig. 2. The whole work flow of the intelligent elevator system.

floor information to the elevator remote dispatching system. Then the elevator remote dispatching system obtains the elevator stop oor information through the load evaluation and similarity matching method. In the meanwhile, the stop oor instruction is sent to the elevator local control system. The local control system controls the elevator to the corresponding oor according to the instructions (Fig. 1).

3.1 Application Layer

As it is shown in Fig. 3, users utilize a WeChat applet to realize the remote call to the elevator. After the WeChat applet, via Bluetooth, obtains the user' floor information and get connected with the server, the user could select the target floor on it. Then the WeChat applet sends the obtained data, namely the user's present and target floor information, to the cloud platform, where the user's request data and the running status of the elevator are monitored in the real time.

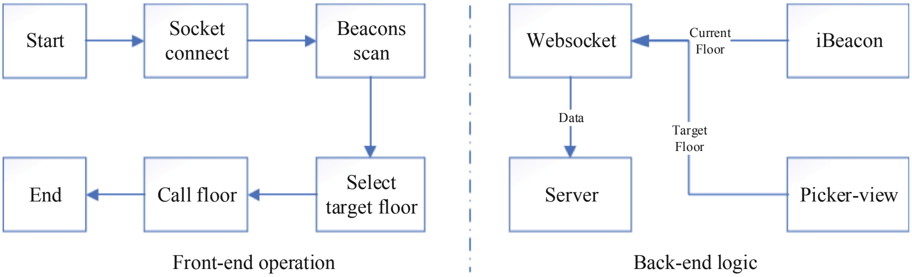

Fig. 3. The user interface design of the mobile mini program.

3.2 Perceptual Recognition Layer

The serial port instruction from the microchip unit is used to control the NB module to receive data. The operation process of the elevator is simulated on the single chip microcomputer, and the corresponding data is displayed on the Organic Light-Emitting Diode (OLED) screen. Meanwhile, the real-time operation data of the elevator is uploaded, by the NB-IoT module, to the cloud platform, where the latest call data is downloaded. The specific process of simulated elevator operation is as follows. When a user has hall request, judge the position of the elevator relative to the user, thus it is concluded that the direction of the elevator. The elevator operates to the user's floor. After opening and closing the door, the user is successfully received. Then, judge the current position of the elevator relative to the user's target floor, thus it is concluded that the direction of the elevator. The elevator operates to the user's target floor, that is, the user successfully reaches the destination.

3.3 Network Construction Layer

iBeacon is a low-power Bluetooth technology. The iBeacon device transmits signals, and the portable device of the user receive and freeback signals. There are four main data of iBeacon: Universal Unique Identifier (UUID), Major, Minor and Measured Power. UUID can create a new identifier for the new service. If the service provider can match the available service with this UUID, it will return a response. NB-IoT is a new technology in the field of IoT, which supports cellular data connection of low-power devices in Wide Area Network (WAN) so that NB-IoT is also known as low-power WAN. Compared with wired or cellular data transmission, NB-IoT has the advantages of low power consumption and easy installation, which is more suitable for the real-time monitoring of elevators. Compared with 4G, NB-IoT can also satisfy a large number of connections. When the iBeacon device transmits signals, the software of the client confirms the UUID of the iBeacon device at first. After the confirmation, the floor information is identified by the major value in the signal and the current floor is indirectly judged by the Received Signal Strength Indication (RSSI) value. And then the floor information is sent to the cloud server through the websocket API. NB-IoT is responsible for data communication between STM32 and cloud server.

3.4 Cloud Computing Layer

The cloud platform has three main functions: real-time elevator monitoring, remote elevator request and scheduling optimization. First, the cloud platform receives the information about the elevator location, operation status and the status of the other sensors through UDP protocol and stores them in the database. The elevator operation database Elevatordata contains the fields such as ElevatorFloorElevatorStateElevatorSpeedNumber_of_People, etc. The web interface reads the data in the database and presents the corresponding data of the elevator in a visual form. Second, the cloud platform obtains the users' call data including the users' present and target floor through websocket protocol, receives the elevator data through UDP protocol and stores the user data and the elevator data into the database. The user call database contains the fields UserFloorTargetFloorProcessedinElevator. Then, the following full load algorithm is used to judge whether the elevator is full. The fuzzy clustering algorithm is used to calculate the scheduling scheme. And finally the dispatching result and full load signal are sent to the elevator.

Scheduling of Elevators. The elevators scheduling procedure is shown as below in Algorithm 1. $E_{FULL\_LOAD\_CONDITION}$ stands for the full load condition of the elevator, n stands for the current number of people in the elevator, $E_{USER\_NUM\_THD}$ represents the number of people judging the elevator to be full, X stands for the number of invalid stop of the elevator, and m is the number of people in the elevator after it was last opened or closed. This algorithm can solve the problem of invalid stop of elevator floor. When the elevator is full

Algorithm 1. Elevators scheduling procedure

```
while TRUE do
  if $E_n < E_{USER\_NUM\_THD}$ then
    if $E_m$ is equal to $E_n$ then
      $E_X$=$E_X$+1
      if $E_X > E_{INVALID\_STOP\_THD}$ then
        $E_X$=0,$E_{FULL\_LOAD\_CONDITION} = 1$
      else
        $E_{FULL\_LOAD\_CONDITION} = 0$
      end if
    else
      $E_X$=0,$E_m$=$E_n$,$E_{FULL\_LOAD\_CONDITION} = 0$
    end if
  else
    $E_{FULL\_LOAD\_CONDITION} = 1$
  end if
end while
```

but not exceeding the predetermined threshold, it will not stop the elevator floor by floor but not able to carry more people, resulting in the waste of power and time.

Fuzzy Clustering of the Elevator Callings. In the scene of the elevator calling by various users, it is necessary for the central control to coordinate the concurrent user callings in order to provide more services. In this paper, a fuzzy clustering based method is adopted to achieve it. As illustrated in [13], clustering is the classification of similar objects into different groups, or more precisely, the partitioning of a data set into clusters, so that the data in each subset share some common trait, often proximity according to some defined distance measure.

In this paper, the input matrix to be fuzzy clustering is $Elevator_i$ $(i = 1, 2, \ldots, n)$ which represents for attribute aggregation about all users requesting for elevators E_i. It is defined as

$$Elevator_i = \begin{pmatrix} U_1 \\ U_2 \\ \cdots \\ U_n \\ E_1 \\ \cdots \\ E_l \end{pmatrix} = \begin{pmatrix} C_1 & D_1 & T_1 \\ C_2 & D_2 & T_3 \\ \cdots & \cdots & \cdots \\ C_n & D_n & T_n \\ E_1 & E_1 & E_1 \\ \cdots & \cdots & \cdots \\ E_l & E_l & E_l \end{pmatrix} \tag{1}$$

where U represents for the elevator calling by users, C represents for the floor that the user locates, D represents for the relative location with the elevator, T is the user target floor, n represents all users waiting for the elevator, and l stands for the number of the elevators.

After the data source is formed, it comes to the core of the decision-making algorithm which is fuzzy clustering. The matrix **Elevator** is fuzzy similar but it maybe not fuzzy equivalent. For the classification of similar objects into different groups, it is necessary to make **Elevator** convert to $\mathbf{Elevator}^*$. As **Elevator** is fuzzy similar, it exists minimum $k\,(k \leq n, k \in N)$ to make $t\,(\mathbf{Elevator}) = \mathbf{Elevator}^k$. Meantime, for all $l\,(l \leq l, l \in N)$, there definitely takes the equation form $\mathbf{Elevator}^l = \mathbf{Elevator}^k$ so that $t\,(\mathbf{Elevator})$ is fuzzy equivalent matrix $\mathbf{Elevator}^*$.

4 System Evaluation

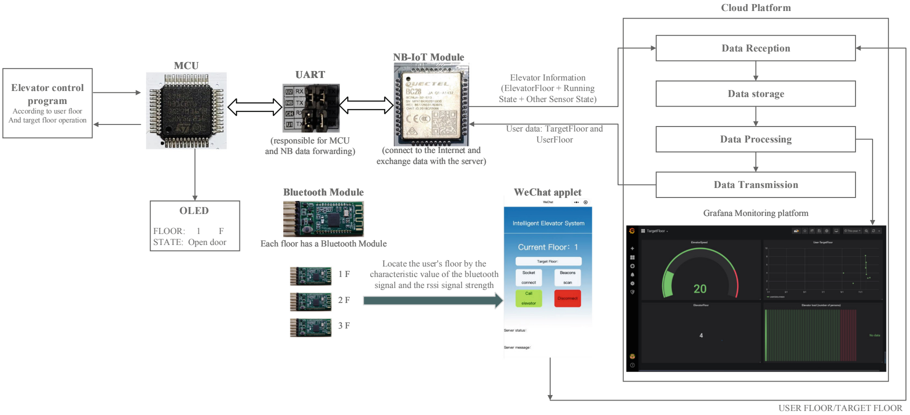

Fig. 4. The real intelligent elevator system.

At present, the elevator protocol is not open to the public, so the operation process of the elevator is simulated on the single chip microcomputer. STM32 is adopted not only because of its high performance and low power consumption but also because of its fast running speed, rich interface and rich communication modules (Fig. 4).

The specific operation process is as follows. Users select the target floor by utilizing the Wechat applet in the portable device, mobile phones, for instance. Then the background process of the applet scans the Bluetooth broadcast signal at the elevator waiting area. The users' floor location are identified by the characteristic value and RSSI signal strength, and the users' present and target floor information is sent to the elevator remote dispatching system. Then the call elevator data is stored in the database. The server sends the new user request, including the target floor and the user's floor data to the simulated elevator control terminal STM32 and sends the elevator floor and the running status of the elevator to the server. The Grafana monitoring platform displays the running status of the elevator and the user's call request in the real time.

5 Conclusion

Through the low power wireless networks including the NB-IoT and Bluetooth iBeacon technology, an intelligent elevator system is proposed with remote calling and cloud scheduling in this paper. The remote elevator calling is presented for the general portable equipment, which not only reduces the management cost, but also solves the problem of inaccurate identification of the number of incoming persons. The elevator dispatching center in the cloud receives the call data of users and the running state of the elevator at the same time, and judges the full load through multi factors. The design reduces the number of ineffective elevator door opening and closing, while improving the running efficiency of the elevator. The user call data and elevator data are presented on the web through the visual interface, which can give the maintenance personnel a more comprehensive and intuitive elevator operation health state, making the elevator maintenance become more active, rather than passive maintenance after failure or accident. The elevator entity that installed the proposed system will be tested for future work.

References

1. Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., Ayyash, M.: Internet of Things: a survey on enabling technologies, protocols, and applications. IEEE Commun. Surv. Tutor. **17**(4), 2347–2376 (2015). https://doi.org/10.1109/COMST.2015.2444095
2. Chang, B., Catpinar, S.F., Jayasuriya, N., Kwatny, H.: Control of impaired aircraft with unanticipated elevator jam to a stable level flight. In: 2019 IEEE 15th International Conference on Control and Automation (ICCA), pp. 543–548, July 2019. https://doi.org/10.1109/ICCA.2019.8899603
3. Farooq, M.O., Wheelock, I., Pesch, D.: IoT-connect: an interoperability framework for smart home communication protocols. IEEE Consum. Electron. Mag. **9**(1), 22–29 (2020). https://doi.org/10.1109/MCE.2019.2941393
4. Fernández, J., Cortés, P., Muñuzuri, J., Guadix, J.: Dynamic fuzzy logic elevator group control system with relative waiting time consideration. IEEE Trans. Ind. Electron. **61**(9), 4912–4919 (2014). https://doi.org/10.1109/TIE.2013.2289867
5. Gao, Y., Xu, X., Lu, J., Sun, Z., Chen, S., Liu, Z.: Energy consumption braking characteristics analysis for multi-car elevator system. In: 2019 22nd International Conference on Electrical Machines and Systems (ICEMS), pp. 1–6, August 2019. https://doi.org/10.1109/ICEMS.2019.8921491
6. Ge, H., Hamada, T., Sumitomo, T., Koshizuka, N.: Intellevator: enhancing elevator system efficiency by proactive computing on the traffic flow. In: 2019 IEEE 1st Global Conference on Life Sciences and Technologies (LifeTech), pp. 80–84, March 2019. https://doi.org/10.1109/LifeTech.2019.8884070
7. Hacks, M.: Huawei elevator networking: connecting millions of elevators. J. Big Data Era **11**, 12–19 (2018)
8. Hangli, G., Hamada, T., Sumitomo, T., Koshizuka, N.: Precaelevator: Towards zero-waiting time on calling elevator by utilizing context aware platform in smart building. In: 2018 IEEE 7th Global Conference on Consumer Electronics (GCCE), pp. 566–570, October 2018. https://doi.org/10.1109/GCCE.2018.8574706

9. Ikuta, M., Takahashi, K., Inaba, M.: Strategy selection by reinforcement learning for multi-car elevator systems. In: 2013 IEEE International Conference on Systems, Man, and Cybernetics, pp. 2479–2484, October 2013. https://doi.org/10.1109/SMC.2013.423
10. Kwon, O., Lee, E., Bahn, H.: Sensor-aware elevator scheduling for smart building environments. Build. Environ. **72**, 332–342 (2018)
11. Li, J., Siddula, M., Cheng, X., Cheng, W., Tian, Z., Li, Y.: Approximate data aggregation in sensor equipped IoT networks. Tsinghua Sci. Technol. **25**(1), 44–55 (2020). https://doi.org/10.26599/TST.2019.9010023
12. Lin, S., Luo, F., Zhang, Z., Wang, X., Chen, Z.: Elevator scheduling based on virtual energy level transition of floors. In: 2019 Chinese Control Conference (CCC), pp. 2274–2278, July 2019. https://doi.org/10.23919/ChiCC.2019.8865576
13. Macario, V., de Carvalho, F.d.A.: An adaptive semi-supervised fuzzy clustering algorithm based on objective function optimization. In: 2012 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), pp. 1–8, June 2012. https://doi.org/10.1109/FUZZ-IEEE.2012.6251345
14. Mangera, M., Panday, A., Pedro, J.O.: Ga-based nonlinear pseudo-derivative feedback control of a high-speed, supertall building elevator. In: 2019 IEEE Conference on Control Technology and Applications (CCTA), pp. 982–987, August 2019. https://doi.org/10.1109/CCTA.2019.8920625
15. Mishra, K.M., Krogerus, T.R., Huhtala, K.J.: Fault detection of elevator systems using deep autoencoder feature extraction. In: 2019 13th International Conference on Research Challenges in Information Science (RCIS), pp. 1–6, May 2019. https://doi.org/10.1109/RCIS.2019.8876984
16. Nazarova, O., Osadchyy, V., Shulzhenko, S.: Accuracy improving of the two-speed elevator positioning by the identification of loading degree. In: 2019 IEEE International Conference on Modern Electrical and Energy Systems (MEES), pp. 50–53, September 2019. https://doi.org/10.1109/MEES.2019.8896414
17. Rodrigues, D.V.Q., Rodriguez, D., Wang, J., Li, C.: Smaller and with more bars: a relay transceiver for IoT/5G applications. IEEE Microw. Mag. **21**(1), 96–100 (2020). https://doi.org/10.1109/MMM.2019.2945151
18. Strang, T., Bauer, C.: Context-aware elevator scheduling. In: 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW 2007), vol. 2, pp. 276–281, May 2007. https://doi.org/10.1109/AINAW.2007.131
19. Sun, M., Tay, W.P.: On the relationship between inference and data privacy in decentralized IoT networks. IEEE Trans. Inf. Forensics Secur. **15**, 852–866 (2020). https://doi.org/10.1109/TIFS.2019.2929446
20. Tartan, E.O., Erdem, H., Berkol, A.: Optimization of waiting and journey time in group elevator system using genetic algorithm. In: 2014 IEEE International Symposium on Innovations in Intelligent Systems and Applications (INISTA) Proceedings, pp. 361–367, June 2014. https://doi.org/10.1109/INISTA.2014.6873645
21. Wang, H., Fapojuwo, A.O.: A survey of enabling technologies of low power and long range machine-to-machine communications. IEEE Commun. Surv. Tutor. **19**(4), 2621–2639 (2017). https://doi.org/10.1109/COMST.2017.2721379