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# 사물 인터넷과 액세스 코드 배포 기반의 경제적인 공공 자전거 공유 시스템의 설계 및 구현

랄손 바즈라차러[1] · 정종문[2] · 황민태[2*]

# Design and Implementation of Cost-effecive Public Bicycle Sharing System based on IoT and Access Code Distribution

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## 요 약

본 논문에서는 사물 인터넷과 액세스 코드 배포가 가능한 스마트폰 애플리케이션을 기반으로 하는 공공 자전거 공유 시스템을 설계하고 구현하였다. 스마트폰 사용자는 애플리케이션을 사용해 자전거 대여 신청을 하면 서버에서 암호화된 액세스 코드를 받게 되고, 이 코드는 도킹 스테이션에서 자전거의 잠금을 해제하는 용도로 사용되며 자전거 반환 시에도 동일한 코드가 사용된다. 스테이션의 하드웨어 프로토타입은 라즈베리 파이, 아두이노, 키패드, 모터 드라이버와 같은 사물 인터넷 디바이스를 기반으로 하여 구현되었으며, 스마트폰 애플리케이션은 기본적으로 액세스 코드를 이용한 공유 자전거 대여 및 반환 기능과 더불어 사전에 자전거를 예약할 수 있는 부가 기능도 포함하고 있다. 구현한 시스템을 테스트 해 본 결과 3~4초의 매우 적은 지연시간을 보여주고 있어 효율적인 시스템임을 알 수 있다. 본 시스템은 단일 콘트롤 박스에서 다수의 자전거를 관리할 수 있도록 구현할 수 있으며, 사용자 역시 스마트폰 애플리케이션만으로 시스템을 이용할 수 있어 비용 효율적이라 여겨진다.

## ABSTRACT

In this paper, we design and implement a public bicycle sharing system based on smart phone application capable of distributing access codes via internet connection. When smartphone user uses the application to request a bicycle unlock code, server receives the request and sends an encrypted code, which is used to unlock the bicycle at the station and the same code is used to return the bicycle. The station's hardware prototypes were built on top of Internet devices such as raspberry pi, arduino, keypad, and motor driver, and smartphone application basically includes shared bike rental and return functionality. It also includes an additional feature of reservation for a certain time period. We tested the implemented system, and found that it is efficient because it shows the average of 3-4 seconds delay. The system can be implemented to manage multiple bikes with a single control box, and as the user can use a smartphone application, this makes the system more cost effective.

**키워드** : 액세스 코드, 자전거 공유, 경제성, 사물 인터넷, 스마트폰

Key word : Access Code, Bicycle Sharing, Cost-effective, IoT, Smartphone

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## Ⅰ. Introduction

Science and technology today has brought drastic changes in various fields including modes of transportation. An environment friendly and energy efficient transportation is a necessity for today. A forecast done by UN population fund states that by the end of 2030 AD, 60% of the world population would live in cities. This urges to mainly resolve issues related to transport and implement a smarter transportation system [1]. Necessary changes have already been implemented in various developed countries considering transport-based rules and vehicle management system, making it more environment friendly and green energy efficient. However, we have not been able to see a change in global scale when it comes to this matter. Thus, a shared bicycle-system which is cost effective and environment friendly can be applicable globally, making a bigger impact tackling pollution and conserving our surrounding.

In general, bicycle sharing system is a commercially based renting system, via which a user can get a bicycle for specific amount of time from a station and can park anywhere in the station closest to them. The system is highly efficient when it comes to transportation, replacing fuel-based vehicles [2]. Various conditions need to be considered when it comes to bicycle sharing. We need to study the size, population density, topography and climate [3]. This helps in planning efficient placement of stations, as well as knowing the highest traffic area of a particular city. We also need to study what kind of technology will be used for the system. And finally, the total installation, operation and maintenance cost of the system, as well as system status and system security needs to be maintained. In this paper, we have focused how IoT technology can be implemented in bicycle sharing system to address environmental and transport related problems. We also encourage this system to be used in developing countries, helping the people by providing alternate means of transport as well as reducing fuel consumption.

In this paper, Chapter 2 presents a related research done on bicycle sharing system, Chapter 3 introduces the main idea and architecture of an IoT based bicycle-sharing system. Similarly, Chapter 4 presents system application along with various sub topics explaining about the working methodology. Chapter 5 gives a short evaluation on system performance and lastly, Chapter 6 gives the conclusion and future works that can be implemented in the system.

## Ⅱ. Related Research

We know that population today has been increasing tremendously. This makes use of vehicles go higher in number, causing various health problems related to air pollution. Moreover, higher concentration of dust particles and harmful gases are found in cities, expecting the rate of premature mortality to double by the year 2050 [4,5]. Unplanned city transportation and use of old vehicles emitting harmful gases are widely seen around the world. Therefore, it seems that a proper public bicycle sharing will make a vital impact in the environment and people’s lifestyle as a whole.

We all are familiar with the term Internet of Things, which is highly discussed topic and gaining a lot of attention from every field. The main ideology behind IoT is using various day to day things around us, and making them able to communicate with each other with the help of intelligent addressing technology [6]. The application of IoT is possible in different fields, namely traffic management, industrial areas, home automation, medical assistance etc.

Another study based on IoT [7] discussed about the various architectures that are used in urban areas. It provided a survey on various technologies and protocols for urban IoT as well as technical solution and best practices for a smart city-project. Various web service approach and server management for IoT system was also discussed in the study.

Mobility in urban areas mainly focuses on travelling on network of roads, explaining high use of a certain bicycle route compared to others [3]. This describes necessity of a proper station and vehicle distribution. But latency and public inconvenience might occur during redistribution of bicycles.

It is also equally important that a bicycle sharing practice is accepted socially as well as culturally [8]. In this study, we were able get a detailed knowledge based on political and social lifestyle. Interview with experts around Europe helped to further get a deeper insight on legislative and systematic work flow of a society and necessary changes for implementing a new mode of transportation.

Bicycle security and management is also one of the major topics when it comes to bicycle sharing [9].We need to know how securely a bicycle can be tracked and the details of current user who has borrowed or parked the bicycle. A Kiosk system is highly preferred when compared to most of the bicycle share systems being used currently in developed countries.

Various sharing systems are already implemented all over the cities in developed countries. Paris currently is operating a bicycle sharing system called “Velib”, that operates all over the city, with 1800 stations [10]. Similarly, Amsterdam too has a lot of bicycle sharing systems, among which “URBEE” is commonly used [11]. Technologically more advanced than other system, the bicycles in this system use in-built smart lock that can be unlocked by the code obtained from the application. One of the globally used bike sharing system called “O-BIKE”, is currently running in more than 10 countries. However, the system runs without a specific station for parking and can be parked anywhere in a designated O-Bike parking zone, public bicycle or motorcycle parking space.

Even though the bicycle systems used in these cities are highly effective and popular, high technology or lack of proper management system of the bicycles make them unsuitable for all the countries. One of the major hurdle is placement of stations in an optimum location for easy access of users [12]. Also, it is necessary to address problems like bicycle rebalancing in stations with time [13]. As the satisfaction of users depend on various factors like household income, location of stations, users perception of bike-sharing, it is necessary to address these sectors as well [14]. Therefore, we need a more cost and technologically efficient system to run in developing countries as well as a proper parking and verification methods for maintaining a certain level of security. Also, separate routes for bicycle ride and necessary infrastructures need to be developed to provide safer rides for the public [15].

## Ⅲ. PROPOSED ARCHITECTURE AND REQUIREMENTS OF THE SYSTEM

### 3.1. Requirements of the system

Before practical implementation of the system, all the necessary requirements are needed to be considered. Below in table 1 shows the configuration requirements of the system. These requirements include stations in remote locations, live server, user application and efficient data communication between them for signal analysis and transfer.

**Table. 1** Basic requirements of the system

| Requirements | Details |
|---|---|
| Installation of remote bicycle stations | Motor locks, docks, sensors, signal drivers etc |
| Remote server | A server running on remote location maintaining database for the system |
| Mobile application | Providing users with an application for easy location of stations and registration of bicycles |
| Analysis and two way transmission of data from stations | Efficient way to send/receive signals from stations to the main server and vice versa |
| Maintaining a stable network connection | Using a wireless network technology for |

### 3.2. Architecture and Work Flow

Fig. 1 shows a basic architecture of the proposed system. We see that the main server is present in a remote location, maintaining the database for the system. The database manages both the user data as well as bicycle data, according to its placement in respective stations. A smartphone based application used by user is connected to the server via internet. The communication between them is shown via dotted line in the figure. Similarly, multiple stations in desired location are maintained with docks. Each station will have a control box, consisting of a circuit board to communicate with the server via internet. The communication between them is shown with solid lines in the figure. The parked bicycles can be rented by users anytime. Also, any of these docks, if empty, could be used to park bicycles already rented by the user. The application system firstly asks for user authentication. Upon successful authentication, user will be able to choose the bicycle from desired station. The desired bicycle access code can be obtained only if the user account is valid ie, the account is recharged and validity date exceeds the current date. Similarly, in the station, the obtained access code from the application is used to lock or unlock the bicycle. If the user enters wrong code or the dock is not empty in case of parking, an error is displayed and user is allowed to enter again.

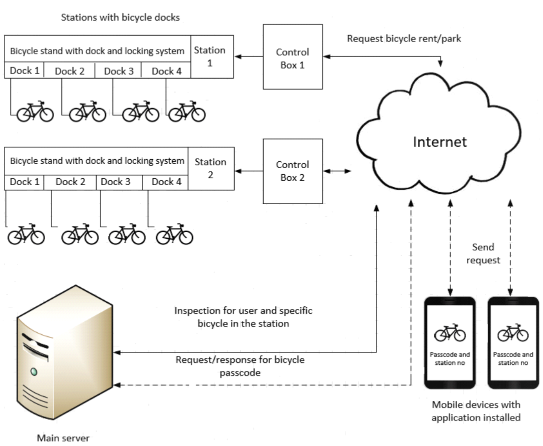



**Fig. 1** Basic architecture of the proposed system showing stations with bicycle docks, a main server, mobile application and basic data transmission methodology

## Ⅳ. IMPLEMENTATION OF THE PROPOSED SYSTEM

The basic configuration of bicycle sharing system is shown in fig 2 below. As the system needs ubiquitous network communication, an LTE network is used. In case of absence of an LTE network, GSM or 3G network can also be used. The control box in each station is connected to an LTE modem that connects it directly to the internet. Remote server is also connects to the same LTE network via modem. The data sent to the web server from user application or any station is analyzed and then the request is approved or disapproved by the server. Accordingly, the database running in the server side is updated. To make the system eco- friendly, solar cells are used to power all the stations.

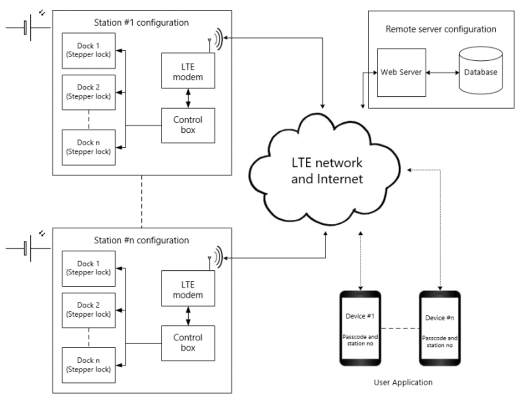



**Fig. 2** Basic configuration overview of the system

### 4.1. System Configuration

The system mainly consists of 3 configuration sections, namely server, stations and the mobile application. Each of these sections are developed with different hardware and software setup. A detailed explanation about it is given below.

#### 1) Server Configuration

In this system, we have used a web server using LAMP(Linux, Apache2, MySQL5, PHP) package. The server is connected to the internet via router with a 4G

LTE dongle, along with necessary port forwarding to connect to the required device or stations. Using LTE network, the server connects to the bicycle stations and mobile applications running in user's devices. Fig 3 below shows the server running actively.

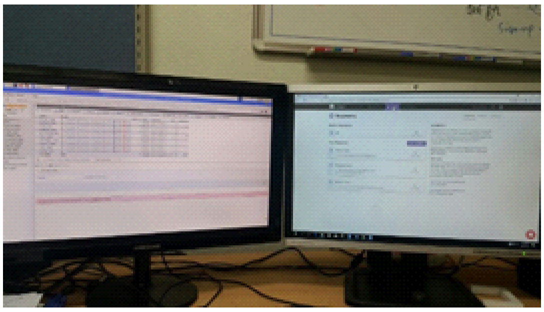


**Fig. 3** Web server running actively showing database tables and one signal push notification application

2) Station Configuration

Every station in the system consists of its own control panel (control box), powered by solar cells. The hardware in the box consists of an Arduino connected to various motor drivers along with a stepper motor, as well as an LCD, a keypad and a Raspberry Pi. A 4G LTE modem is connected to the Raspberry Pi for data communication. C, PHP and python programming languages were used to code the software in this system. Fig 4 shows the control box with keypad and LCD display whereas Fig 5 shows the hardware configuration inside the control box consisting of an Arduino, Raspberry Pi, 4G dongle and motor drivers. Control box in each station is programmed according to the number of docks it maintains to lock the bicycles. Fig 6 shows a 3D designed dock for each bicycle. The number of docks for bicycles can be increased or decreased according to public demand. A mechanical motor system for lock/unlock is set up in each dock. The data as characters from Arduino is sent to the Raspberry Pi by serial communication. Using an encryption algorithm, the encrypted data is then sent to the server via LTE network as an HTTP request. The request is responded by the server, sending a character of data sequence to the control box. According to the response, the received data is decrypted and then sent from Raspberry pi to Arduino, and the result is displayed as well as locking/unlocking task, as requested by the user.

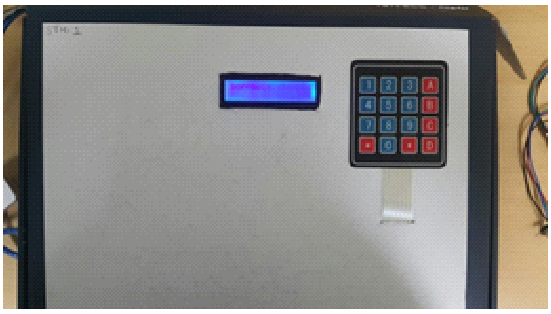


**Fig. 4** Control box with a 2x16 LCD and a keypad

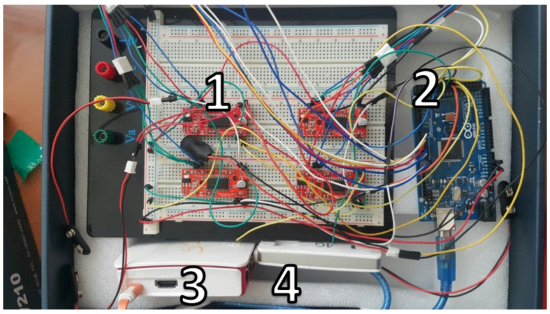



**Fig. 5** Hardware configuration of control box (1. Motor Driver, 2. Arduino Mega, 3. Raspberry Pi, 4. 4G Modem)

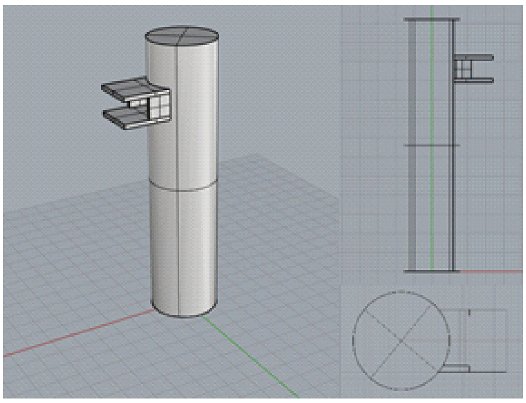
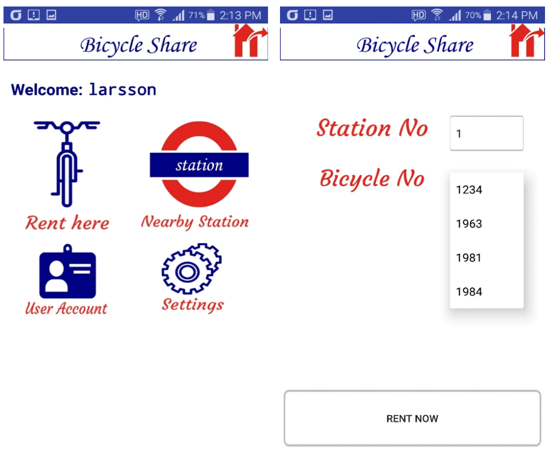


**Fig. 6** 3D design of a bicycle dock with perspective, top and front view

3) Application Configuration

The application for this system is developed in Android Studio integrated development environment, and Apache web server and MySQL database management system. The front-end designing of the application is done using XML(Extended Markup Language) and Adobe Photoshop CC whereas the back-end programming is done in Java programming language.

The main function of this application is helping user to register a bicycle for use and obtain an encrypted access code for a specific bicycle. In this system, the user can register for free. However, the account is not activated unless he/she recharges for the service. The recharge service can be done by bank transfer as well as international payment gateway like Mastercard. For developing countries, the service might not be available everywhere. So, we can use domestic gateways in that case. For example, in Nepal, a gateway called eSewa can be used which can provide this service [16]. Recharge can be done via the application itself. For tourists, the service can be provided for certain number of days as well. Fig. 7 shows the UI (User Interface) of the application [17]. Four simple options in startup page guides user to either rent a free bike from any station, use GPS to check the nearby station, recharge or see history of user accounts and change the current settings of the user details.



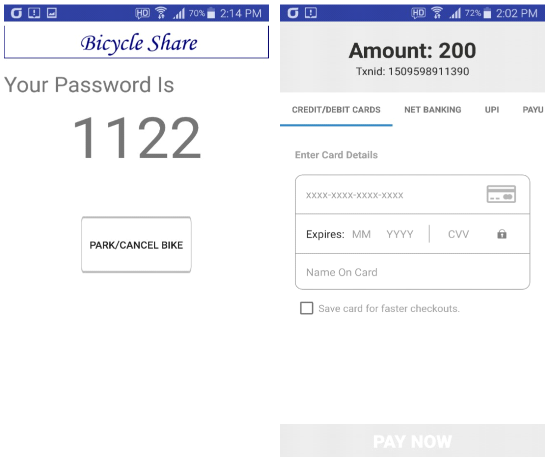




**Fig. 7** UI of the application with Main Page, Bicycle Registration, Access Code and Payment System

4.2. Operating Mechanism of the System

The detailed operational method of this system is shown in fig 8. below. Firstly, the user uses his/her application to login and check the nearest station using the nearby stations option. After routing himself/herself to the location , the user can request server for an access code for desired bicycle from the station. If he/she is in a hurry, the bicycle can be registered to use prior to reaching the station. This disables other users to use the specific bicycle. However, registration can be done for maximum of 15 minutes. If the user is unable to unlock the bicycle within that time frame, a push notification is sent to the user stating that the code is no longer valid. The access code received can be entered to the control box of the station via keypad. The entered value from keypad is encrypted for data security in Raspberry Pi. Using the LTE network, the data is sent as packets to the base station. Once the packet is sent to the internet, it routes itself to the remote Web Server, running on a specific port, with the help of port forwarding. Thus, the web server receives the HTTP request and decrypts the data sent with it. Verification of the data is done by running a query into the database.

After data verification, the query result is provided as character data type by the database. The Web Server then encrypts the result and sends it back as response to

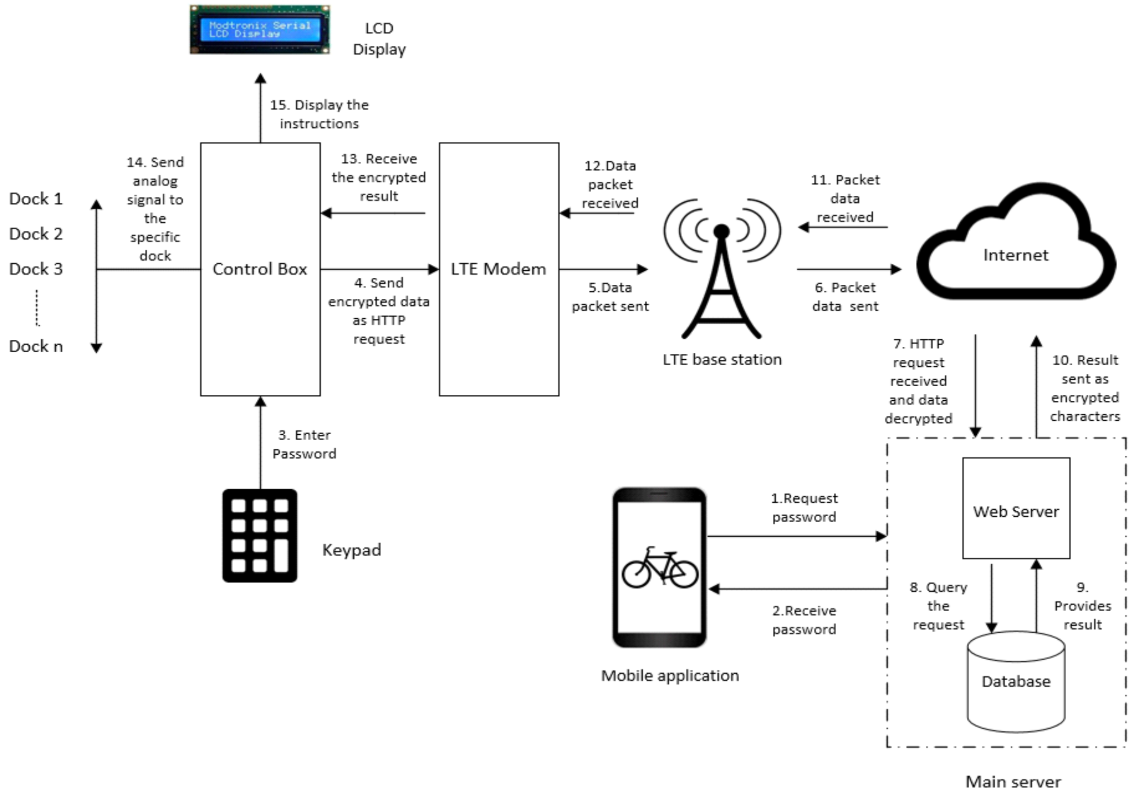



**Fig. 8** Detailed operation mechanism of the system showing data request and signal flow along the mobile application, web server and remote bicycle station

the LTE base station via internet. The base station receives the data packets and forwards it to the station. Therefore, the control box receives the encrypted result. The result is then decrypted and the character result is obtained. The character is then processed by the control box and verifies which bicycle to unlock. A signal is then sent to the specific dock and bicycle is unlocked. The unlocked dock number is then displayed on the LCD screen and requests user to take the bicycle. Similarly, after user reaches the destination station, he/she can park the bicycle in any free dock using the same code received earlier. The same series of operation takes place in parking as it did while renting the bicycle. After the use of service, the trip and user details are maintained in the database for future verification and quantitative analysis of the system. This also helps in maintaining system security and data warehousing. If the user desires to view the number of times he/she rented the bicycle, it is possible via the application itself. Comments and rating is possible after completion of every ride via smartphone application.

To maintain system security, all the data transmission done between the system components are encrypted using 256 bit Rijndael (AES) encryption [18]. To further enhance the system security, the cipher key used in encryption is also encrypted so that the level of threat from data spoofing can be minimized. In case of theft or physical vandalism of the station, cctv cameras can be maintained in each station powered by solar panels. The source code for server, station and smartphone application can be viewed in the github link [19].

## Ⅴ. SYSTEM PERFORMANCE

The performance evaluation of this system was done in two ways, ie calculating the time taken for communication between station and server, and time required to communicate between smart phones running the application and the server. To measure the performance, four of the stations along with control boxes were maintained. A trial of 100 times were performed by these stations at the same time to communication with the server. A temporary database was maintained in the Raspberry Pi inside the control box to record the time difference between data sent and received by the station. Fig. 9 below shows the average time required by the stations for successful communication and data transmission. Similarly, a trial was also performed to check the time needed to communicate between smartphones and the remote server. In this case, ten sets of trials, each with varying number of smartphones running the application to access the same station’s bicycle was done. Similar to the previous trial, an SqLite database was maintained inside each smartphone application to record the difference of timestamp between outgoing and incoming data, ie while communicating with the server. The average time required after the trial is shown as a result in the bar graph below in fig. 10. The tests showed that the time required was very minimal even when the number of smartphones running simultaneously, or number of stations accessed were fluctuated.

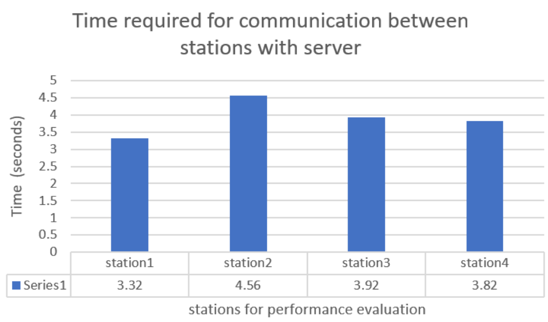



**Fig. 9** Evaluation of average time required for communication between stations and servers

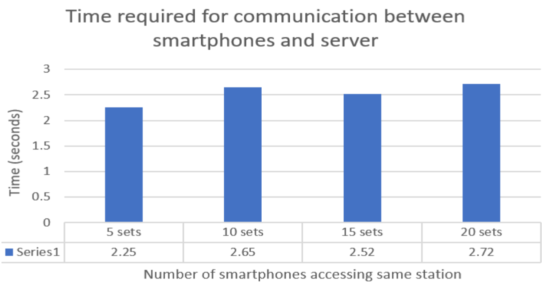



**Fig. 10** Evaluation of average time consumed for communication between smart phones and server

## Ⅵ. CONCLUSION

We know that the cities across the world are getting crowded and the public transportation system is not able to meet the demands of public. Moreover, air pollution due to large number of public vehicles has caused the air quality level to get worse. To tackle these problems and make the city eco-friendly, we made a Bicycle Sharing System implementing IoT. We discussed that using technology like IoT and application-based sharing system, it is possible to encourage people to travel more on bicycles and use less public or private means of transportation. We also discussed the detailed implementation process of this system, making it cost effective and environment friendlier. However, as the system requires good communication network, discussions for an effective implementation of a good telecommunication and IoT based system is very necessary so that it can be implemented in third world countries as well.

IoT technology being used in developing countries might lead to overall changes in conventional lifestyle as well. Bicycle sharing systems being used by other countries have seen a lot of positive impact in their society. Even though challenges are inevitable for application of this system, this system might just be the solution to many of the problems faced today in cities concerned with environment and means of transportation.

In the future, we will attempt to use NFC cards as a payment alternative, multiple options for payment, and we will also investigate towards better security system for data transmission and a well-organized redistribution system of the bicycles among the stations.

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