Design and analysis of a software and hardware system to detect a person's presence on premises using Wi-Fi technology

I L Reva, A A Bogdanov, E A Malakhova

Novosibirsk State Technical University, 20 Prospekt K. Marksa, Novosibirsk, Russia

Abstract. The paper describes the design of a software and hardware system to detect a person's presence on premises and analyses its operating. The authors have designed the concept of the software to be installed on the controlling device and described its features. Based on Wi-Fi routers, the designed software and hardware system is a physical access control system that detects and positions devices with Wi-Fi adapters or people in the coverage area. The designed system has been tested.

Keywords: Local positioning, physical access control system, premises protection, triangulation, Wi-Fi networks, interference, Wi-Fi hotspot, premises security.

1. Introduction

The issues related to the premises security and access control are still relevant, especially the issues related to the movement control on premises. Due to the rapid development, widespread using and moderate price of Wi-Fi technologies, the equipment to setup wireless networks can be used to detect and position a person's presence on premises.

As many buildings have fully operated enterprise and public Wi-Fi networks, we propose to use the already built infrastructure to detect presence and location of people indoors, what is certainly more cost-effective than installing a dedicated physical access control system. Furthermore, the security system based on Wi-Fi routers is easy to adjust.

The main task of the system is detecting the appearance of a person on the protected premises; an additional task is to location the person.

To calculate the locations of devices that have a Wi-Fi chipset (i.e., a smartphone), an algorithm based on the intersection of circles has been chosen since this algorithm is sufficient for effectively locating [1].

2. Design of software to detect a person's presence on premises using Wi-Fi routers

Microsoft Visual Studio Code and Open Server have been used to develop the application.

The software of the controlling device is to have the following features:

2.1. Tracking the appearance of an object between two routers (a method of movement detection in the absence of a device).

2.2. Calculation of the coordinates of the detected devices according to the formulae [1]:

$$X = \frac{d_1^2 - X_1^2 - Y_1^2 - d_2^2 + X_2^2 + Y_2^2 - 2*Y*Y_2 + 2*Y*Y_1}{2*(X_2 - X_1)} \quad (1)$$

$$X = \frac{d_2^2 - X_2^2 - Y_2^2 - d_3^2 + X_3^2 + Y_3^2 - 2*Y*Y_3 + 2*Y*Y_2}{2*(X_3 - X_2)} \quad (2)$$

$$X = \frac{d_1^2 - X_1^2 - Y_1^2 - d_3^2 + X_3^2 + Y_3^2 - 2*Y*Y_3 + 2*Y*Y_1}{2*(X_3 - X_1)} \quad (3)$$

2.3. Detecting the object's appearing inside the coverage area.

2.4. Comparing the received device name to the registered names of the devices from the database.

2.5. Showing the calculated coordinates on the building plan.

2.6. Notifying if the device is detected on premises.

2.7. Observing the object's movement over the time, viewing the current locations of the devices.

The controlling device receives data on signal levels from the devices with a Wi-Fi chipset and the device ID (mac address). The software on the server connects to the database and compares:

- The average signal level to the signal received between the routers within a certain period of time;
- The level of the signals received from the routers to the reference value (so it is possible to calculate the distance between the router and the device).

The software then uses the algorithm of three-circles intersecting with the radius equal to the distance calculated based on the signal levels to determine the area in which the device is located, and draws a point in the center of the obtained area.

In addition, the software compares the signal on the control routers to the routers, between which the intruder is monitored. If the signal level is greater than the critical value, the system notifies that a person is detected.

The user should be able to download the floor plans to place routers on the plan, as well as to set the average signal level between the routers and the signal strength of the router (zero measurement).

To implement the method for detecting the movement of the person with no device that has Wi-Fi chipset, the option to receive the normal signal level between the two routers within a specified time to calculate the average signal level in the absence of objects between them and transmission.

The software interface has been written in HTML and CSS, the link between the front-part and the back-part is implemented using JavaScript, namely the jQuery framework. We have opted for it as it has many ready-made tools for interacting with php [2]. The logic layer is in PHP, database management system – in MySQL.

The server sends commands to run the script, which can be used to get the information from routers. Then the program fetches the files formed by the router, reads the information and obtains the information about the signal levels.

3. Hardware implementation of the movement detection system using Wi-Fi technology

To implement the security system, the following devices are required to be consolidated into one infrastructure for operating testing:

3.1. Three hotspots (the most accessible spots are selected) TP-Link Router TL-MR3020 [3].

3.2. Three USB-drives of 2 – 4 GB. In our case, a 4 GB drive is used.

3.3. Switch TP-Link TL-SG108 [4].

3.4. Three 10-meter long Gigabit Ethernet cables.

3.5. The personal computer acts as a device configuring communication with the server to process the data being received.

The test infrastructure scheme is shown in figure 1.

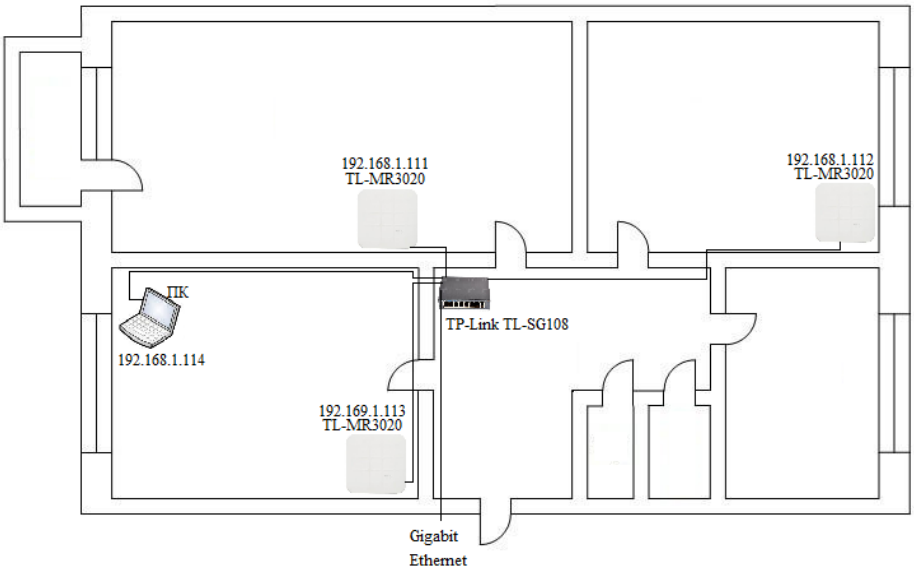

Figure 1. Scheme of the test infrastructure.

In the built infrastructure, routers operate in WISP mode so that one can simultaneously configure the parameters of each device over Ethernet, and, at the same time, they can work as hotspots.

4. Router software (firmware)

The firmware by TP-Link with limited feature-set is initially installed on the router. It is enough for common users and allows working in the hotspot mode, but it is not suitable to solve the task. To do this, we have used the open source operating system OpenWRT. It is Linux-based system that allows designing new packages and install existing necessary for operation.

The router software has the following features:

1. Scanning. This includes information about the surrounding hotspots, such as network identifier (SSID), MAC address, and received signal strength (RSSI). These data are required for motion registration.
2. Intercept Probe Request from client devices in the coverage area of the hotspot. Data formation to implement the positioning feature-set on the server.
3. Encapsulation. Creating a file with the data necessary to implement one of the two feature-sets.
4. Operation in hotspot mode. Each router is to carry out its direct task, i.e. to serve as a hotspot for client devices.

Since the router must operate in two modes, two interfaces have been designed and configured:

- One works in monitor mode, it is used to detect a new device in the coverage are of the router and obtain the necessary data about this device;
- The second works in the hotspot mode, it is used to receive the signal level from the other routers.

To switch the router to the monitor mode, the libraries necessary for working with the Python programming language have been installed.

A script has been written in Python that allows intercepting the Probe Request from the devices and write data about them in a log file that is stored on the router. The script also allows filtering the monitored object. If its mac address is known, the software and hardware system can read the Probe Request sent only by this device. From the resulting file, the control device will use the following parameters:

- mac address (BSS);
- SSID;
- Signal strength (RSSI).

Figure 2 shows the result of the router reading all the mac addresses.

```
[2019-06-04 16:23:16.447665]
Starting scan
Scanning for:00:00:00:00:00:00
Probe Request Captured:
Target: ff:ff:ff:ff:ff:ff Source: 22:08:ca:f3:f4:4b SSID:  RSSi: -77
Probe Request Captured:
Target: ff:ff:ff:ff:ff:ff Source: 22:08:ca:f3:f4:4b SSID:  RSSi: -75
Probe Request Captured:
Target: ff:ff:ff:ff:ff:ff Source: ba:ea:ef:67:1d:f4 SSID:  RSSi: -92
```

Figure 2. The result of the script when reading all mac addresses.

From the interface operating in the access point mode, we receive data to implement feature-set of traffic registration in the absence of the intruder device with a Wi–Fi module. To do this, the command line of the operating system of the router runs the following command: iw dev wlan0 scan | tee -a detecting.txt. The router scans the environment for access points and generates a detecting file.txt, which records all the information received and stores the file in the memory of the router in a directory.

The resulting file is parsed on the server-side, the necessary data is extracted from it and processed to implement the feature-set of motion registration, in the absence of the intruder device in the Wi–Fi module.

To automatise the process of data generation, a bat script has been written that, being run, connects to the router via SSH and performs the necessary commands to generate the files. After that the files are uploaded from the router memory to the server.

5. Implementation of the software to detect a person's presence using the Wi-Fi technology

To calculate the locations of devices that have a WI-FI chipset (i.e., a smartphone), an algorithm based on the intersection of circles has been chosen since this algorithm is sufficient to effectively location [1].

To start working with the software, we should build the infrastructure, measure the power of routers, select the routers between which the control of a person’s appearance will be carried out.

Once the program is started, the window with a list of the rooms can be seen, if the building plan has been loaded beforehand.

The system requires initial configuration of the controling device software. To do this, we should click the "Add floor" button, then load the floor plan, enter the length and width of the floor, the floor name and add routers to the floor using the "Add router" button. In the new window, we should enter the parameters of the router and then drag the router with the mouse to the desired location. The generated list will be displayed on the plan.

The interface for adding a floor is shown in figure 3.

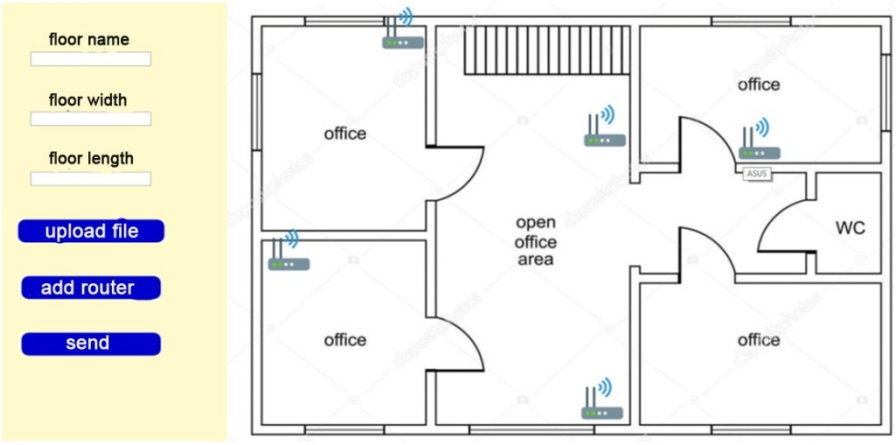

Figure 3. The application interface of adding a floor plan and set routers.

Next, we should set the location of the hotspot on the plan, capturing the desired hotspot and dragging it to the plan with the mouse pointer.

In the monitoring start mode, the point is displayed based on the coordinates calculated by means of the designed mathematical model. After clicking on the hotspot, we can select "Compare coordinates" in the opened window and set the real coordinate, so the system can display the difference. When a person appears with a device that has a Wi-Fi chipset or a person appears between the routers designed to detect an object without it, the system informs about the event threatening the security via interface.

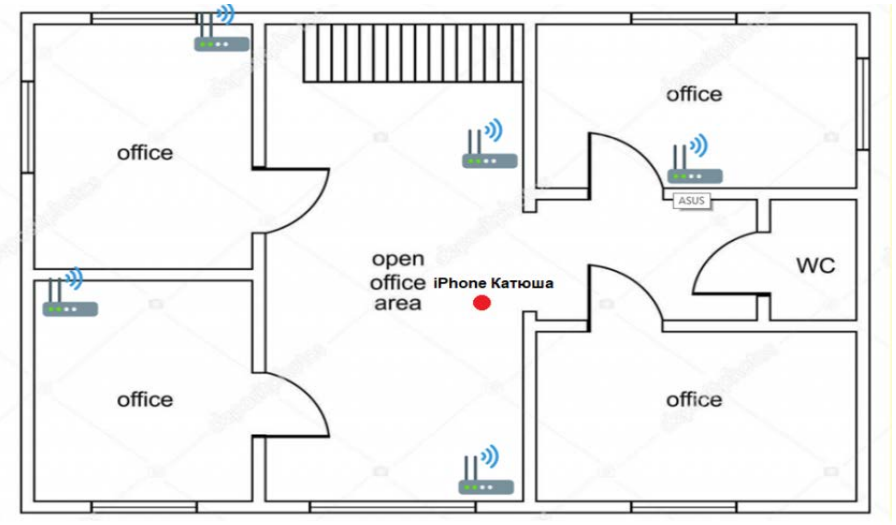

Figure 4. The application interface displaying the coordinates on the plan.

The structure of the main database tables is shown in figure 5.

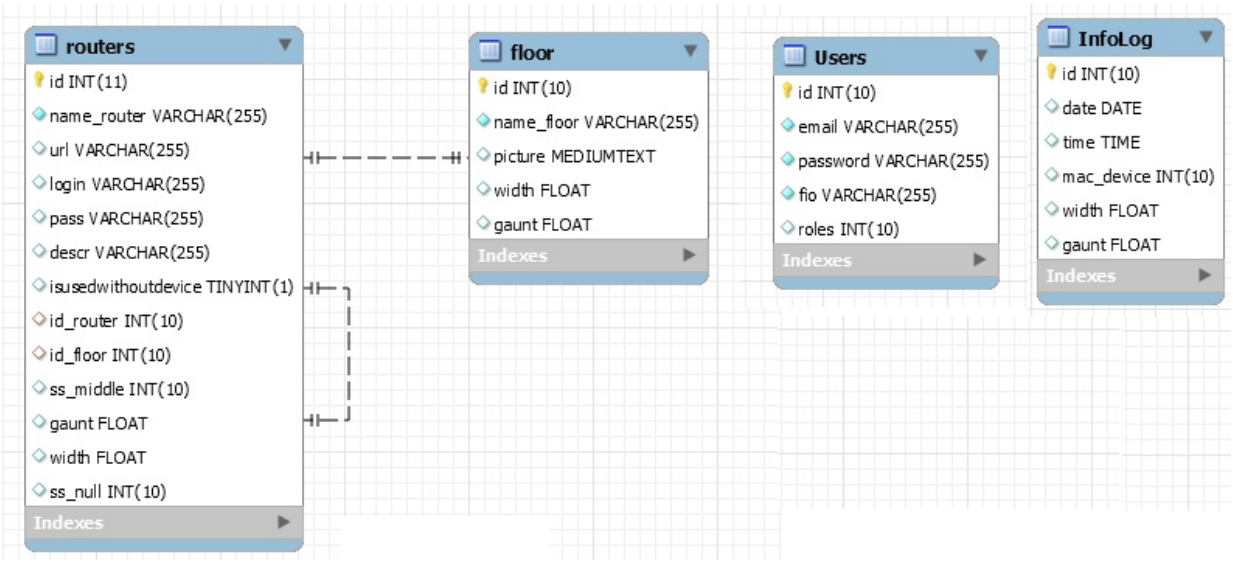

Figure 5. EER-diagram of the main tables in the database.

The following PHP controllers are implemented for the system operation:

- The parameters are saved in the database floor:

```
<?
include_once 'connection.php';
 if(isset($_POST['name'])){
     // connect to server
    $link = mysqli_connect($host, $user, $password, $database)
       or die("Error" . mysqli_error($link));
        // character escaping for mysql
     $name = htmlentities(mysqli_real_escape_string($link, $_POST['name']));
     $picture = htmlentities(mysqli_real_escape_string($link, $_POST['picture']));
     $width = htmlentities(mysqli_real_escape_string($link, $_POST['width']));
     $gaunt = htmlentities(mysqli_real_escape_string($link, $_POST['gaunt']));
      // creating query string
     $query ="INSERT INTO floor (name_floor,picture,width,gaunt) VALUES
('$name','$picture','$width','$gaunt')";
     // processing the query
     $result = mysqli_query($link, $query) or die("Error " . mysqli_error($link));
     if($result)
     {
       echo "<script>console.log('floor data in database')</script>";
     }
     // closing the connection
     mysqli_close($link);
 }
?>
```

- Saving router settings to the database:

```
<?
include_once 'connection.php';
 if(isset($_POST['name'])){
     // connect to server
    $link = mysqli_connect($host, $user, $password, $database)
       or die("Error" . mysqli_error($link));

     // character escaping for mysql
```

```
        $name = htmlentities(mysqli_real_escape_string($link, $_POST['name']));
        $descr = htmlentities(mysqli_real_escape_string($link, $_POST['descr']));
        $name_router = htmlentities(mysqli_real_escape_string($link, $_POST['name_router']));
        $vertical = htmlentities(mysqli_real_escape_string($link, $_POST['vertical']));
        $horizontal = htmlentities(mysqli_real_escape_string($link, $_POST['horizontal']));
        $query1 ="SELECT id FROM floor WHERE name_floor='$name'";
        $result1 = mysqli_query($link, $query1) or die("Error " . mysqli_error($link));
        $row = mysqli_fetch_array($result1);
        $id = $row['id'];
          // creating query string
        $query ="INSERT INTO routers (name_router,descr,id_floor,gaunt,width) VALUES
('$name_router','$descr','$id','$vertical','$horizontal')";
        // processing the query
        $result = mysqli_query($link, $query) or die("Error " . mysqli_error($link));
        if($result)
        {
          echo "<script>console.log('router data in database)</script>";
        }
        // closing the connection
        mysqli_close($link);
    }
    ?>
```

- Connection to the database;
- Getting information about the routers from the database;
- Getting information about the floor from the database;
- Parsing files generated by the routers and sending the received information to JSON. Reading from the file:
- File received from the interface in the hotspot mode:
    - mac address (BSS) – a value between "BSS" and «(»;
    - SSID – a value between "SSID: » and « »;
    - signal strength (RSSI) – a value between "signal: "and "dBm".
- File received from the interface in the monitoring mode:
    - mac address (BSS) – a value between "Source: » and « »;
    - SSID – a value between "SSID: » and « »;
    - signal strength (RSSI) – a value between "RSSI: » and « ».
- Adding users to the system;
- Running scripts to send the commands to routers.
  JS does the following:
- Moves the routers on the plan;
- Loads and displays a floor plan image;
- Displays the plan and routers when selecting the floor;
- Calls the controllers;
- Compares the received signal level with the normal signal between the routers. If the signal level is greater than the critical value, the system informs about the possible appearance of the intruder;
- Calculates the location of the device according to the data obtained from three routers; otherwise, the system informs about the appearance of the device in the coverage area of the routers;
- Checks user rights;
- Informs about the registered event that violates the safety.

The algorithm for calculating the location of the device by the received levels of signals from three and more routers:

- From the database we get the power of the routers (zero measurement);
- We get the radius of the spheres calculated based on the received signal level and the power of the router (zero measurement);
- The value of the radius is rounded up to two decimal places (the value in meters);
- Then we find the coordinates of the intersection of circles (x_{ij};y_{ij});
- We determine the area of intersection of all circles: determine the intersection points of the circles (x_{ij};y_{ij}) for which the radius from the center is less than or equal to all the radii of the spheres;
- Then we determine the coordinates of the point at which some segments intersect between these points.
- We draw a point based on the found coordinates.

If it is not possible to determine the location of the device, the system does not draw a point but adds information about the found device.

When a new device appears, the system warns and adds information to the security Alert message (InfoLog) table.

6. The results of system testing

We tested the software and hardware system for movement detection of a person without a device that has a Wi-Fi chipset when a person moves between the tested routers. To detect the movement, the variation value has been set to 4 dBm, so if the received signal level is greater than the value of the normal signal level by 4 dBm or more, the system warns about a safety violation on premises. The results are presented in table 1.

Table 1. The test results of detecting the movement of an intruder in the absence of the device with wi-fi adapter.

Distance between the routers (m)	Normal signal level (dBm)	Movement conditions	Received signal level (dBm)	Variation value (dBm)	Movement detection result
1.5	-29	The object is between routers	-37	8	Registered
		The object slowly passes between routers	-33	5	Registered
		The object is moving quickly between routers	-30	1	Not registered
2.5	-37	The object is between routers	-44	7	Registered
		The object slowly passes between routers	-41	4	Registered
		The object is moving quickly between routers	-37	0	Not registered
4	-43	The object is between routers	-52	9	Registered
		The object slowly passes between routers	-47	4	Registered

Distance between the routers (m)	Normal signal level (dBm)	Movement conditions	Received signal level (dBm)	Variation value (dBm)	Movement detection result
		The object is moving quickly between routers	-44	1	Not registered

During the testing, the variation in signal level is found to depend on the speed, size and weight of the person when an intruder appears between the routers:

- The faster the intruder moves between the routers, the harder is to track the variation in the signal level.
- Larger objects attenuate the signal between the routers greater and the signal level variation is higher.

The problems may be solved the following way:

- The difficulty of tracking the variations in the signal strength during rapid movement is due to the time of scanning the network and running the command again. This problem can be solved by limiting the list of routers to scan, so that the speed of the command processing will take less time.
- It is better to install routers at a height lower than the average height of a person or in places where an open door will not prevent receiving a signal from the router.
- With minor variations, the system does not register movement on premises.

We shall test the method of movement detection if a person has a device with a Wi-Fi chipset. The results are presented in table 2.

Table 2. The test results of movement detection of the intruder with the device that has a wi-fi adapter.

Received signal levels, (dBm)	Detection result	Positioning result	Calculated point (m)	Real point, (m)	Measurement error (m)
-50, -45, -42	Device detected	Location determined	(4,2;2,4)	(3,8; 2,3)	0.4
-35, -60, -56	Device detected	Location determined	(0,8; 1,1)	(0,6; 1;5)	0.5
-62, -56, -	Device detected	Location not determined	-	-	-
-45, -60, -40	Device detected	Location determined	(3,1; 3,3)	(2,5; 3,8)	2
-49, -30, -42	Device detected	Location not determined	-	-	-
- , -35, -40	Device detected	Location not determined	-	-	-

During the testing, the device has been detected in all cases, but the location is not determined in all cases for the following reasons:

- The device was not in the range of three routers;
- When calculating the coordinates, the system did not determine the area of intersection of the circles, possibly due to an error in the received signal level from one router.

To reduce location errors, we can increase the number of the routers or add checkpoints to the location method that should be marked when configuring the system. We can also enter a signal level error to adjust the values of the received signal levels. It is also possible to average values of the signal levels received from routers in tense time intervals.

Positioning accuracy also depends on the hardware part of the system infrastructure, i.e. routers. The accuracy of the signal level can be improved by upgrading the hotspots.

The performance of the router depends on its factory settings, but it is also possible to increase it by creating an additional sectors on the USB drive, which must be formatted as swap, and configuring the router so that it identifies the drive as RAM (swap file). It allows speeding up the router.

The signal strength of the hotspots can be increased using an external antenna, if provided by the manufacturer.

The maximum error in determining the location in the test conditions is equal to two meters; the accuracy can be affected by many factors such as radio background, engineering design of the building and others.

7. Results and conclusion

During the work, the following results have been obtained:

- The algorithms of movement detection and location of the device with Wi-Fi adapter are implemented.
- The software and hardware system to detect a person's presence on premises with the use of Wi-Fi hotspot is developed.
- The designed system has been tested and the steps to further improve the accuracy of the system are determined.

When performing the work, it was found that the device with the Wi-Fi adapter is detected in all cases, but the location is not determined in all cases due to the following reasons:

- The device was not in the range of three routers;
- When calculating the coordinates, the system does not determine the area of intersection of the circles, possibly due to an error in the received signal level from one router.

The maximum error in determining the location under test conditions is equal to two meters, the accuracy can be affected by many factors such as interference, engineering structures of the building and others.

The laboratory experiments have shown that:

- The system records the movement of a person in cases of his appearance between the control routers;
- The system detects a device with a Wi-Fi adapter, and in the case of receiving device signal levels from three or more routers, determines the location and displays the object on the plan;
- The software works in conjunction with the hardware and the accuracy of measurements also depends on the accuracy of determining the signal levels of routers.

8. References

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