Study on indoor Optical-RF hybrid Wireless Access Scheme

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1. Introduction

Motivation

With the development of communication technology, requirement of next generation communication (5G) has changed like scalable service experience and anytime and everywhere communication connect service. In 5G data rate will need increase by roughly 1000 times from 4G to 5G.

In order to meet 5G requires, it also necessary to consider about unlicensed frequency spectrum working in above GHz as millimeter wave or optical wireless communication (OWC).

On the contrary, microwave frequency from hundred MHz to a little of GHz are almost fully occupied, it will be necessary to use unlicensed spectrum, to meet 5G's requirement.

Utilizing unlicensed spectrum communication technology will make 5G network become a highly heterogeneous network, thence how to supporting mobility communication in a heterogeneous network will be an important challenge for 5G system also

Same as LTE handover or other homogeneous network, heterogeneous handover also consider about the quality of service (QoS) of Use ending (UE) for example Signal-to-Noise ratio (SNR) and Receiver Signal Strength (RSS), but due to the different measuring and calculate method, it will be a question to set up a stable policy of handover. It's necessary to consider about the cost of handover, delay and handover reward.

In this article, I will propose a handover scheme for OWC-RF heterogeneous network. Handover scheme will be set up based on UE's communication QoS of indoor environment, first I will find out different QoS changing of OWC and RF communication technology. Then I will set up a stable handover scheme to make UE keep in a better QoS.

Relate work

Visible Light Communication (VLC) technology is a novel optical wireless

communication, it's a complementary technology for indoor environment. Different from millimeter wave communication, it's easier to set up a VLC communication network in indoor area. VLC using Light-emitting diode (LED) devices to provide high data rate connect service.

The research about VLC is begin from 1996, Hong Kong University have a research about imaging communication base on VLC, after that, in they proposed a research about simulation model to simulate performance for indoor VLC communication base on MATLAB, in [] a link analyze model of indoor VLC model has been described , begin from 2015, Fang Wang from Tsinghua University proposed VHO between VLC and WiFi in indoor communication environment

Based on these research, I found there is still points that consider about the problem of handover for mobility UE for indoor situation.

Contribution for the research

In this article, I giver an analysis about the QoS changes through UE si moving in heterogeneous network, proposed handover scheme will not only depends on the QoS but also the duration in order to reduce the delay and cost during the handover. The duration will be decide from the layout of VLC and RF access points and UE's route.

Organization of thesis

In section one, I will explain the background of the study, it will including VLC's characteristics and problem. In second section I explain the Markov decision processing (MDP) to explain handover policy, in section three I will explain the model I used and propose a VHO scheme combine VLC and RF communication technology. At the end I will show the result of the simulation.

2. Background

VLC characteristics

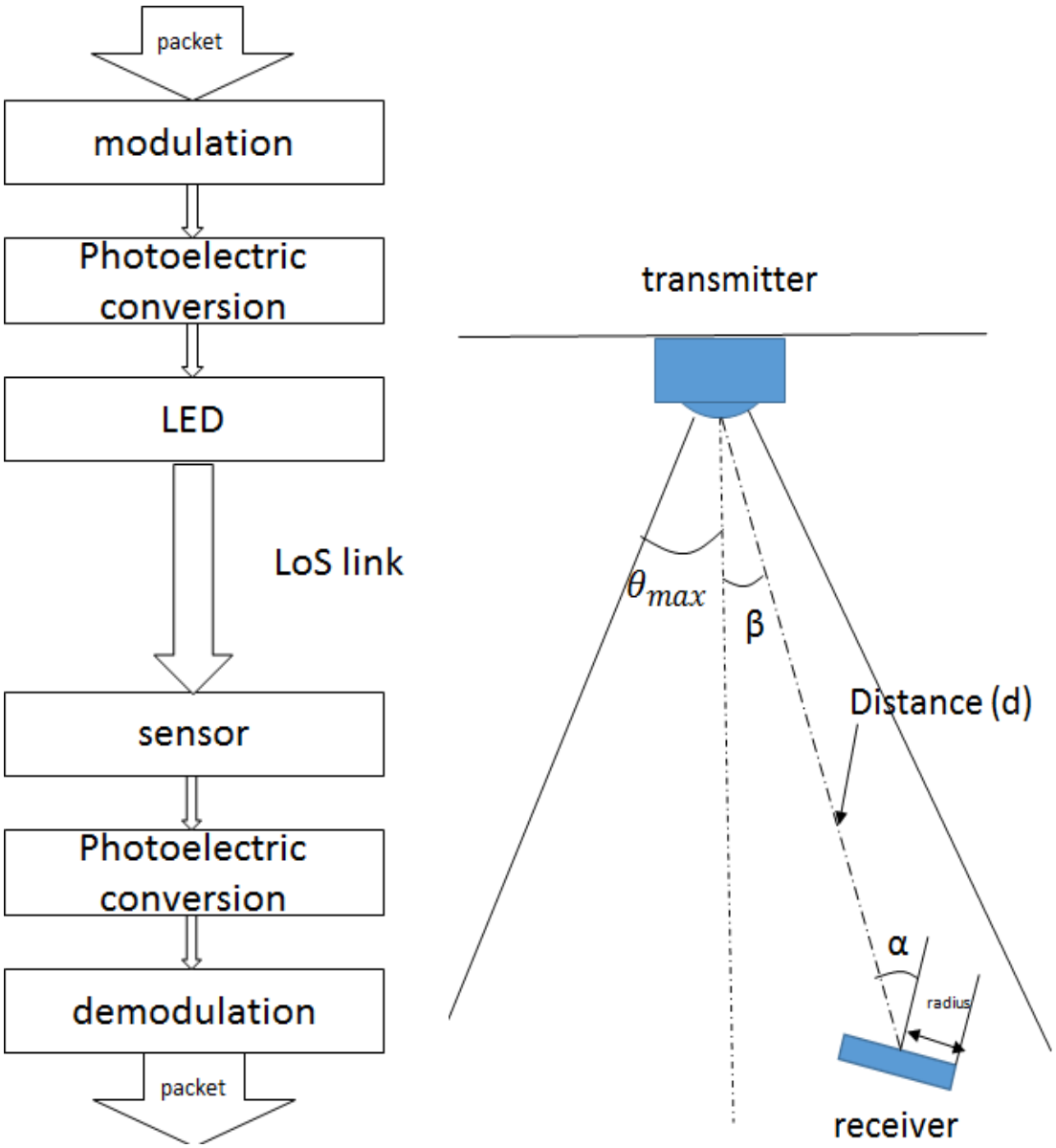
From the 90s, because of the requirement of wireless communication, the research about optical wireless communication (OWC) has begun, according to the working frequency OWC divide in these parts: Visible Light Communication (VLC) and Free Space Optical Communication (FSO) and infrared light communication.

In 2000, Yuichi Tanaka from Keio University proposed a novel indoor VLC establish the research direction, indoor VLC based on LED luminaire.
The characteristics of VLC are including:
1, Low interference from existing communication technology, because of VLC is working in unlicensed spectrum, RF communication will not affect VLC's performance.
2, Low energy cost, consider about the safety of human eyes and LED is also needn't high level energy to drive up, VLC is an energy saving communication technology, however, because of VLC is working in line-of-sight (LoS) link, VLC couldn't support connect link for long distance mobility users.
3, Big capacity, working frequency of VLC is higher than gigahertz, VLC will support a bigger capacity than RF communication technology.
4,Because VLC using LED as transmitter, VLC can support communication service while providing lighting service, it will save the cost of set up the VLC network and make it easy to set up the VLC network in some indoor area where has LED already and needn't too high communication quality (VLC's communication is depends on LED device also because LED through control the luminaire to transmission the information, normal LED we used in day life couldn't support too high frequency shift speed.)

VLC is a chose to support communication for last kilometer, not only for indoor environment but also can be used for outdoor, in outdoor environment, VLC is used for vehicles communication (support connect link between vehicles through LED on the cars, communication distance is still short because there will be more affect in outdoor environment) and support connect for smart traffic communication for example to set up the link between vehicle and traffic light. Distance of outdoor VLC will not exceed 10 meters because of path loss and noise.

In this thesis, I will consider about indoor VLC communication because of indoor environment will support a more stable situation to provides connect service for mobility UE, and in outdoor environment, the noise cause from sunlight or other artificial will affect VLC, but at indoor situation or underground environment, VLC can support better service for UE.

VLC network performance



In order to modulate the data through light, when an LED is in communication station, LED will choosing different luminaire levels to modulate data. The key design requirement for VLC system are lighting, which is main purpose of LED, therefore, VLC system's performance also affected by the impact of LEDs. White LED is the most common LED luminaire for VLC indoor communication this is because of the color of object as seen in white light is easier and it's similar to color of same object in natural light. The white light is produced in these two ways:

1,Blue LED with Phosphor

2 RGB combination

Blue LED with Phosphor is easier to implementation and cost reduction and it is commonly used in the design of white LEDs. However, the phosphor coating is limited communication speed, so RGB combination is preferably in used for communication because it's easy to opportunity to use color shift.
Depends on the type of receiver sensor, VLC can be divide in: imaging VLC and non-imaging VLC.
In imaging VLC receiver will receive the signal through analysis the gray level change, in non-imaging VLC, receiver will use sensitive sensor to receive the signal, different signal correspond different luminance.

Receiver parameter

As figure 2b showed, in order to calculate receiver power, it's necessary to specify the relative position of the transmitter and receiver, and it's necessary to consider about these parameters
d: distance between transmitter and receiver.
R: radius of receiver
$\propto$: angle between receiver normal and transmitter-receiver line (also be called as incident angle)
β: the transmitter viewing angle (also be called as irradiation angle)
θ_{max}: the maximize angle field of view (FOV).
According to parameters, path loss L_l can be shown as

$$L_l = \frac{(m+1)A_r}{2\pi d^2} cos^m(\beta)\cos(\alpha) \quad (1)$$

Where m is means Lambertial emission, m could be got from equation (2)

$$m = \frac{\ln 2}{\ln(\cos\theta_{max}/2)} \quad (2)$$

If use P_t as transmitter power the SNR of VLC could be calculate as

$$SNR = \frac{(RP)^2}{\delta^2} \quad (3)$$

Where δ^2 is given from equation (4) and R is the photodiode responsibility.

$$\delta^2 = 2qRPI_2B + \frac{8\pi kT}{G}\varepsilon AI_2B^2 + \frac{16\pi^2kT\text{ב}}{g_m}\varepsilon^2A^2I_3B^3 \quad (4)$$

In the equation (4)
q: electronic charge
k; Boltzman's constant
P: the light power detect by other detector
I_2 and I_3 : bandwidth factor
T: absolute temperature
ב: FET channel noise factor
g_m: FET transconductance

Channel analysis

1. Multipath propagation fading:

As showed in equation (4) there are not only one LED in the lamp, receiver photodetector may receive multiple LEDs signal in a time. Receiver power can be calculate by summation the received power of each LoS link in receiver's FOV. Beside this, it's also necessary to consider about the impact of reflected path because light will reflectivity of a surface (like floor or wall) equation has already consider about the multipath propagation fading on the receiver as parameter P in equation (4).

2. Shadowing

Because of LoS link, optical link may be shadows are made up some block or object or human in the communication environment. If the link is frequency has block between transmitter and receiver, the performance will be affect by the shadowing in [] they consider about the shadowing cause by human active, indoor VLC shadowing is not studied in literature. Because of the different between VLC and RF communication, shadowing will affect the layout of indoor VLC network. Unlike current deployment they just consider about LED's light purpose.

3. Distance effect and Doppler effect

Because of UE is in moving and distance will change on time, if UE is too far from the transmitter, connect will break out because of the receiver is too small. Same as distance effect, Doppler effect is also cause by UE's movement, but it's only be happen when UE's moving speed upper than 70Km/h, so it will not consider it in this thesis.

In order to reduce the effect of shadowing, there are always multiple LED lamps been map in an indoor environment. But multiple LEDs will cause the multipath propagation fading also.

Modulation method

Different from RF communication in VLC data cannot be encode in phase of the light signal [], in the other words , phase and amplitude technology will unavailable in VLC, the signal of information must be intensity of the emitted light is encoded wave. The demodulation is also depend on direction in the receiver, this is called as IM/DD modulation for VLC.

Some modulation method will be discussed in this chapter and in this thesis I will use ON-Off keying (OOK) modulation for VLC

1,OOK

In OOK, data 0 and 1 means the LED light strength reduction or not because LED is also need to support lighting so couldn't turn off completely.

2, Pulse width modulation (PWM)

While OOK offers a variety of advantages, as simple and easy to implement, there still

have a limitation is its lower data rate, especially when supported different dimming levels. So PWM has been proposed to achieve this work, in PWM, based on dimming levels, pluse's width has been designed and LED always work in full brightness, data rate of modulation signal will be adjusted depends on dimming requirement.

3, Orthogonal Frequency Division Multiplexing (OFDM)

There are a limitation in single-carrier I discussed above, modulation will suffer from high-to-symbol spacing due to non-linear frequency response of VLC. OFDM provides a way to reduce inter-interference as it been used in RF communication. However before apply OFDM in VLC there are multiple question to solve such as how to use OFDM in IM/DD system as VLC.

1. Heterogeneous Handover for existing communication technology

LTE handover

I will introduce some handover method of existing heterogeneous network in this section, including LTE handover method, WiFi handover method. After that I will propose my handover model in VLC-RF heterogeneous network. Handover processing will be described in this section.

Handover in LTE network

With the development of mobile communication technology, LTE and its smooth evolution of LTE-A is being industrial and academic the industry more and more attention from industry and academia. As LTE has been used in recent years, academic research accumulated a large-scale technological innovation, the development and network optimization. The new technologies proposed in LTE-A include carrier aggregation, multi-antenna enhancement, cooperative heterogeneous network deployment, intelligent relaying, self-organizing network, etc.

The LTE-A heterogeneous network refers to a network in which a macro base station (eNodeB) mixes with a series of low-power base station such as femto, pico, etc, and has a certain overlap in coverage area. The introduction of low-power base station can increase network capacity and accommodate more users, but it makes the network structure more complex.

One of main purpose of LTE handover is to provide a faster and seamless handover from source cell to target source. The whole handover process of LTE is affected greatly by the application that the user using, such as long FTP service (as large file downloads etc.), the short interruptions will be tolerated. But for like VoIP calls or video service as well as short-term FTP services (as real-time inter cell phone and image downloads, etc.) user will be sensitive to interruption because of handover .

The handover in LTE is used to solve these question and improve network performance

2.1 Forward Handover

In article [], they discussed a LTE handover process, named forward handover, which increase the whole performance of LTE system,

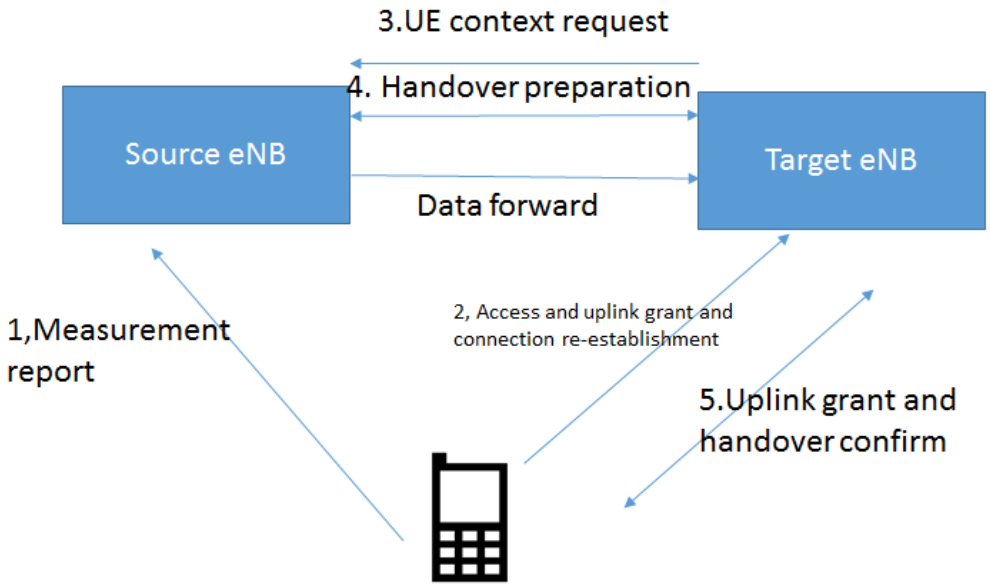


Figure 1 handover processing

As the figure showed eNB means the eNodeB of LTE network, source eNB is current eNB of UE and target eNB is the eNB UE will handover to. The whole processing can be described as :

1, Target get data about UE from source eNB (data forward, this is also why it's be called as forward handover). Although UE could connect well with source eNB or target eNB, target also can get the information about UE. Forward data can increase the success ratio of handover.

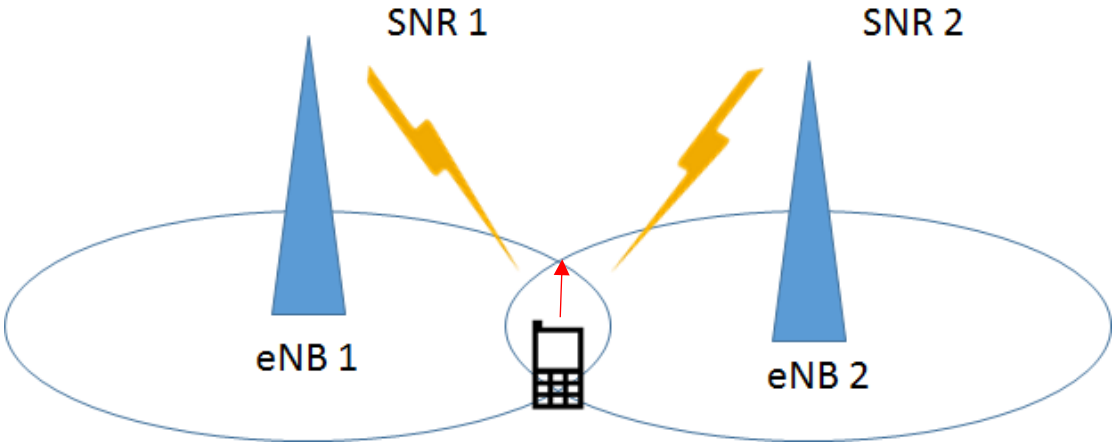
2, UE will transmitter measurement report each over a period of time (it is set up depends on the operators) to source eNB, and the data forward will also be set up according this report, source will transmitter handover command to UE according to measurement report.

3, If UE can connect to target eNB but handover is not begin (UE can transmitter data to target eNB but handover will reduce QoS in current.) UE will transmitter UE's information to target eNB and set target eNB to re-establishment.

4, Target eNB will transmitter UE context request to source eNB if it's not ready for target eNB to handover, UE will connect to other eNB after timer end target eNB is still in establishment, UE will connect to target eNB after target eNB ready.

5, UE will break connect with source eNB because of LTE using hard handover and UE set up connect with target eNB after uplink grant and handover confirm finish.

Because of the new eNB is be chosen through compare SNR or other QoS parameter. The ping-pong switch will happen during LTE handover. As the next figure shown.



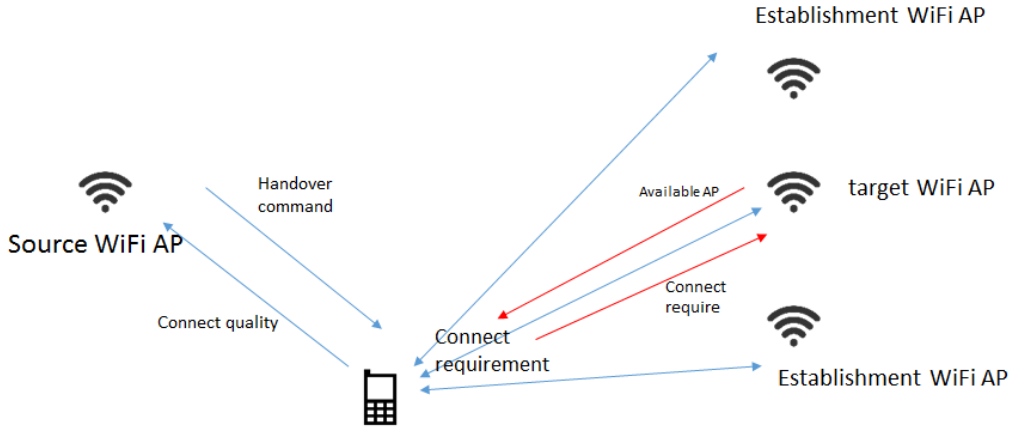
If UE is in the junction are of two eNB, (eNB 1 and eNB 2), and UE is moving following red line, the because of SNR1 and SNR2 changed UE will handover between eNB1 and eNB2 continuously (if SNR1 is bigger than SNR2 UE will switch to eNB1 vice versa, the size relationship will change frequency by the UE moving).
That will waste the energy cost and make the delay of UE.

Handover in WiFi network

Because the increasing demand for network access and the demand for real-time video and audio services for broadband data services
Broadband wireless access technology (WiFi / WiMax) in the academic and business areas are of great concern. Broadband wireless access network technology such as 802.11 protocol specified in the switching process delay in the hundreds of milliseconds to 2 s between the real-time video and audio caused significant pause, affecting the quality of service. The wireless network technology based on 802.11 technology, as the research hotspot of broadband wireless access network, extends the traditional hotspot into hot area. In order to satisfy people's demand of seamless roaming and video and audio service in hot area, Handover technology presents a new challenge.

WiFi is allow to IEEE 802.11protocol and in this protocol, handover is a distributed, terminal-implemented strategy. The distributed method can reduce the load of the network, but increase the consumption of the terminal. 802.11 protocol is described in the 2-layer switch, when the terminal is still within the same subnet roaming, only need to complete the two-tier switch. If the terminal roams between subnets, it needs to complete Layer 3 handover to obtain a new IP address. Mobile IP is commonly used to achieve the three-layer switching protocol, there are currently Mobile IPv4, Mobile IPv6 2 versions. The Mobile IPv6 Fast Handover Protocol for 802.11 networks optimizes the handoff process in 802.11 networks and reduces latency in 802.11 wireless networks.

WiFi Handover process



As the figure shown, WiFi handover including these steps
1, Triggering link: including the trigger condition monitoring (such as channel conditions, network performance) and trigger mechanism (such as the most simple channel quality below a threshold trigger)

2, Scan link: contains the scanning mechanism, the set of available AP;
Select the link: select the final switchable AP;
3, Chosen link: AP will detect user if full or not and communication quality, if AP has free address for a new UE and the communication quality is well also, AP will connect to UE and send the information of AP to set up the connect.
4, Authentication link: if AP and UE begin to set up connect, UE will begin to find AP and authentication, AP will distribute an address to UE.
5, Re-link: UE will link to the target AP after authentication, and begin communication service through target AP until next handover begin.

In WiFi network because the lock of access control mechanism, handover will be trigged if the SNR of UE is lower than a threshold.
The delay because of handover will cause by access point explore, authentication and re-link, the biggest delay is cause for UE to find the target WiFi access point out.

The purpose of WiFi handover including:
1) To maintain the link connectivity, for example to deal with the link unavailable cause of UE's moving.
2) To maintain the performance requirements such as link quality (as SNR of packet loss rate)

In order to meet the requirement above, it's two improve ideas including
1) To reduce the delay cause of handover, mainly is to reduce the number of handover stages or reduce the delay cause from every stage.
2) To disperse the handover process, it is means make stage more simply by using parallel processing and finish the link ahead of time.

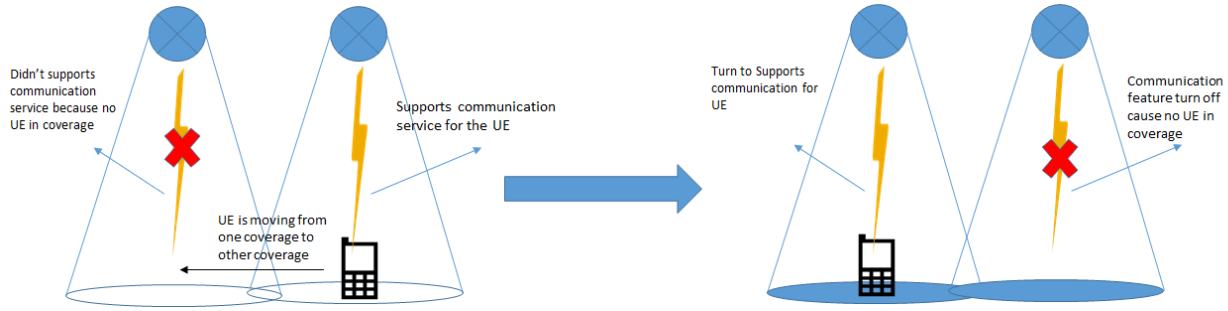
Actually the fast handover of WiFi has already be studied and it also be possible to reduce the delay and improve handover performance through reduce the delay of stage.

Handover in VLC network

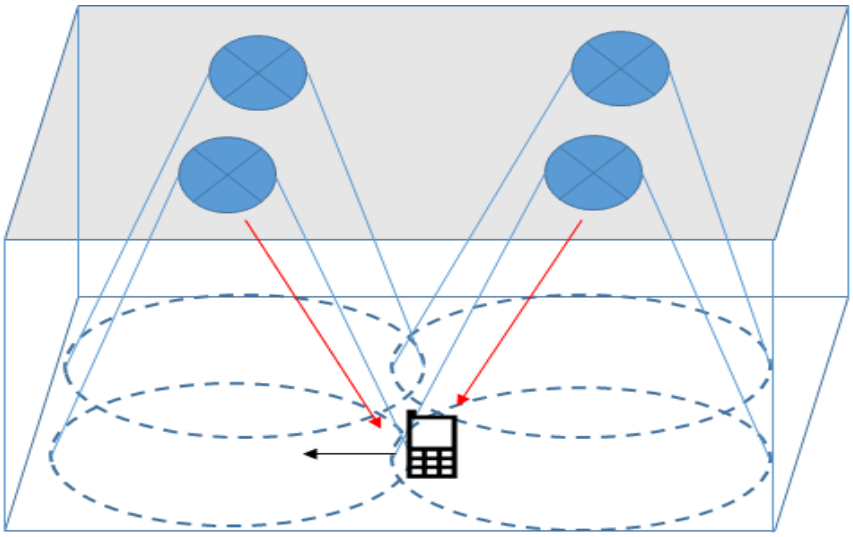
Visible Light communication (VLC) including indoor VLC and outdoor VLC, in indoor VLC network, VLC can used to provide location service and connect service in some area WiFi or other RF communication technologies couldn't supports connect service well.

I will consider about indoor VLC in here, because my propose system of this thesis is based on indoor environment, as WiFi and LTE, handover in VLC network is order to provides a stable communication environment for UE and because of working in Line-of-sight, VLC will also consider about the block between transmitter and receiver. Cause of the same reason, handover of VLC also should consider about the location: closer to transmitter is means better connect quality.

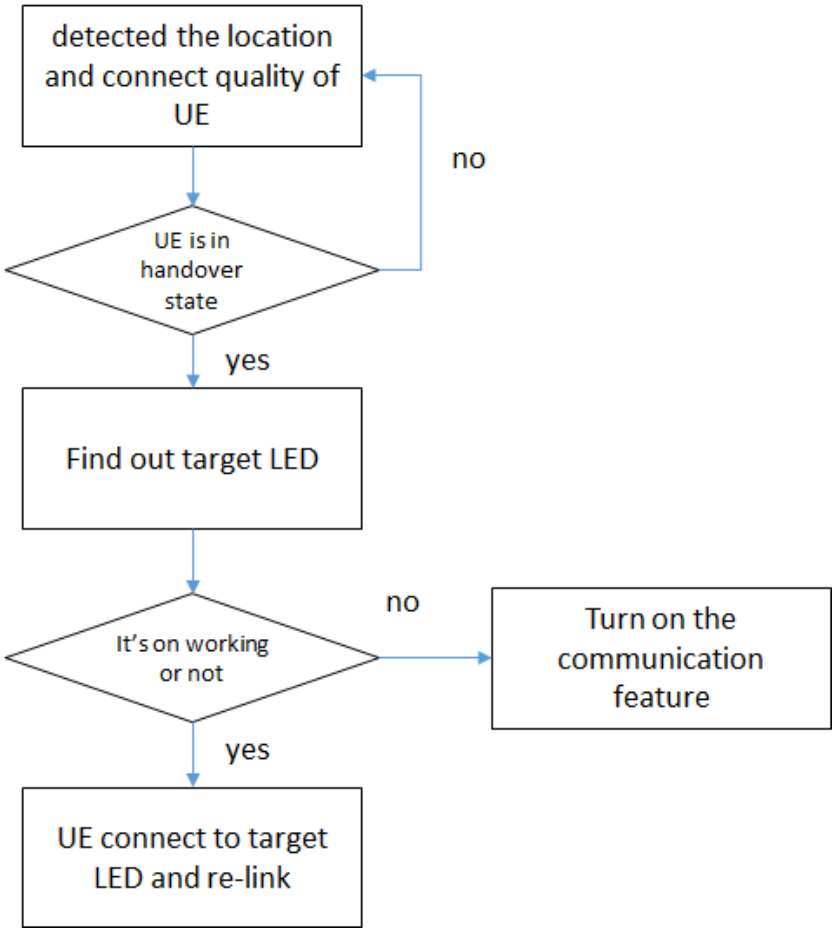
LED is provides the lighting and communication transmission at the same time. In order to save energy, turn off the communication feature of the some LED which didn't connect to UEs and if there are some new UE will coming in the coverage area, turn on the communication feature.



VLC Handover process



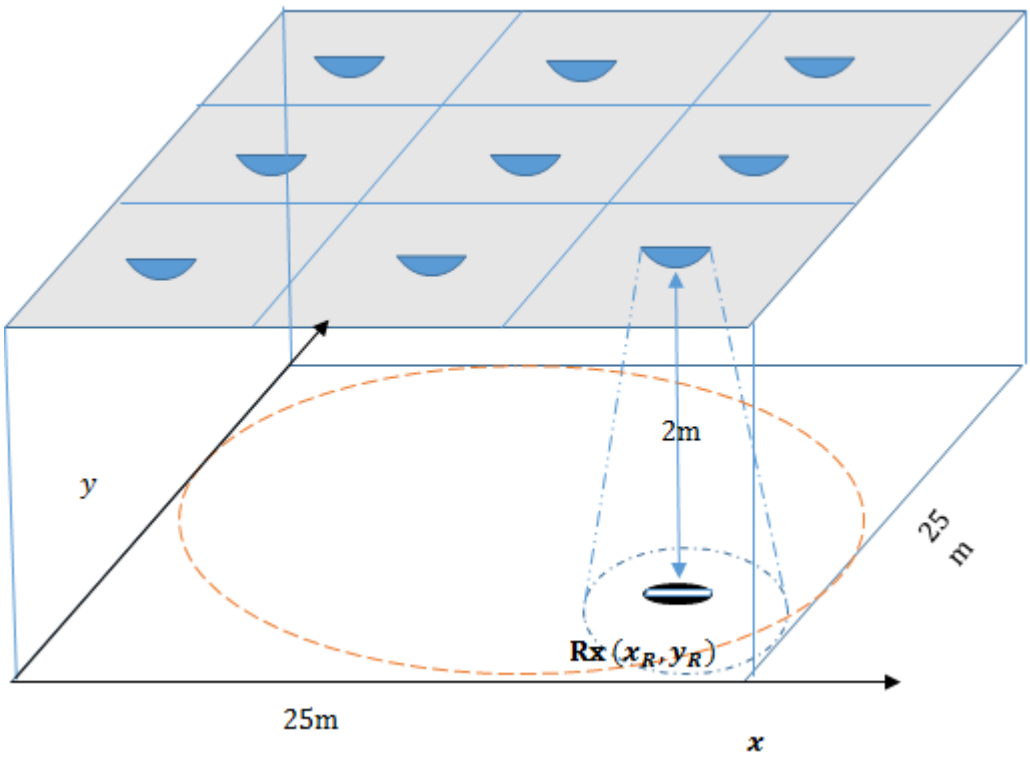
Almost same as handover in WiFi or LTE, handover will happened when UE move from source coverage to target coverage. The whole process can be described as below showed



The handover will begin from access point of LED, and source will find the target LED out for UE, the re-link connect (connect to set up re-link) will also begin from LED.

Because of the short communication distance, UE will handover frequency when UE is moving so it is a importance for VLC to set up a stable handover decision in order to make the UE's QoS better.

Purpose handover



I will set up such an indoor environment, width and length are 25m and high is 3m, consider about the high of human, I assume the receiver is high than 1m from floor, that is means vertical high between transmitter to receiver is 2m.

I set LED transmitter in roof as 9×9 and I also set a WiFi transmitter in the central of the room. When the UE moving in the room, because of the distance increase from UE and LED transmitter the receiver signal strength and SNR will reduce so UE will handover to VLC or WiFi, and I will apply Maklov decision to find out a stable handover policy.

4. Markov decision processing

Markov process is a mathematical model for some complex system, the basic unite of Markov process is state, in the discrete time, and the states of a system will "transition" from one state to other state. We can think system occupies a state when it describe d through the values of variables, and it will be defined as a state in the system, a system makes state transition when it be change from values specified for one state to those specified for another because variable changed.

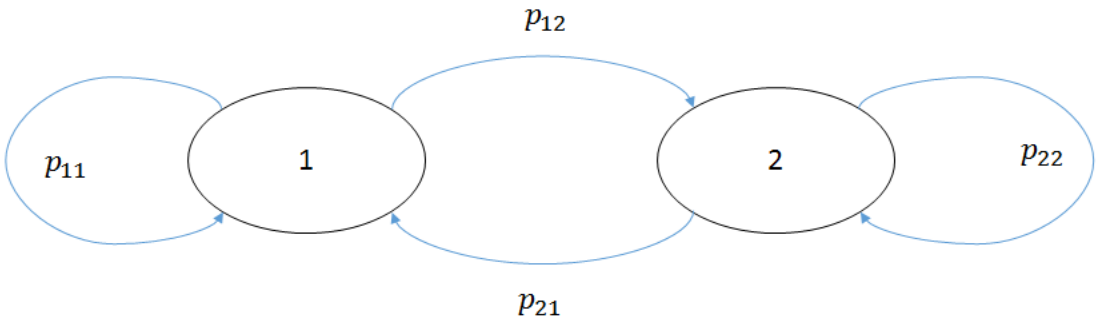
In Markov process I specify the probability of state transition. It is convenient to assume time between two states is a constant. For example, there are N states in the system from state 1 to state N, in the Markov process, if assume p_{ij} is the probability from state I transition to state j, the history of state I will not affect the probability and the summary of probability will be 1 as shown in equation (5)

$$\sum_{j=1}^{N} p_{ij} = 1 \tag{5}$$

And $0 \leq p_{ij} \leq 1$ is also be known from equation (5)

Markov chain

Markov chain described the transition processing and probability between states, a simply Markov chain will be shown in figure



In this sample the probability matrix will be set as

$$p = \begin{bmatrix} p12 & p11 \\ p21 & p22 \end{bmatrix}$$

And if assume states at beginning is q = (1,0) means the system is begin at state 1, relatively, (0,1) is means the system is begin from state 2.
Use state times probability the state after one transition will be known as $[p12, p12]$ after one more steps the state disruption distribution, the state will become approaches a fixed value. If consider about reward, the Markov will can calculate the transition trend of a find result of a transition policy.

The parameter of Markov Decision Processing (MDP) will including
S: states of MDP
P: the probability from a state transition to other state
A: the action, state will change from on state to other state because of the action.
R: the reward of the action.

MDP scheme

the propose of MDP is to find a optional policy, in order to achieve this propose, it's necessary to consider about probability and reward of transitions, after a certain number of transition the state will approaches a probability distribution, and the expected return can be got through time reward and the finally probability distribution.

MDP use value iteration to find the optimal policy out, the whole processing can be described as

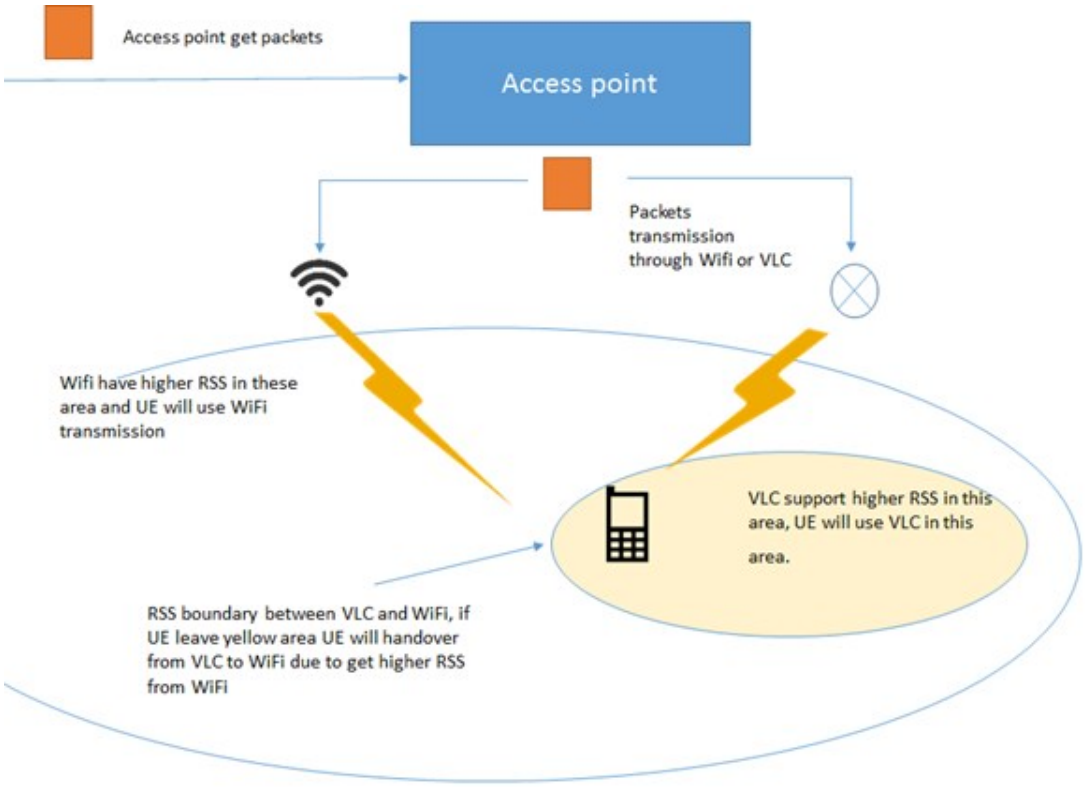
---

% assume S means all state below states, V(s) is the value of state, t is time, A means action
For s$\in S$, V(s) = 0; t = 0
Loop

t = t +1;% for every time
loop s $\in$ S
loop a $\in A$
Q(s) = R(s,a) + $\sum_0^{t-1} V_{t-1}(s)$
End loop
$V_t = maxQ_t(s)$
End loop
Until $|V_t(s) - V_{t-1}(s)| < \varepsilon$ for sϵS

In MDP the action will affect the probability of states, so in order to achieve the optimal policy, it's necessary to find the corresponding action out.

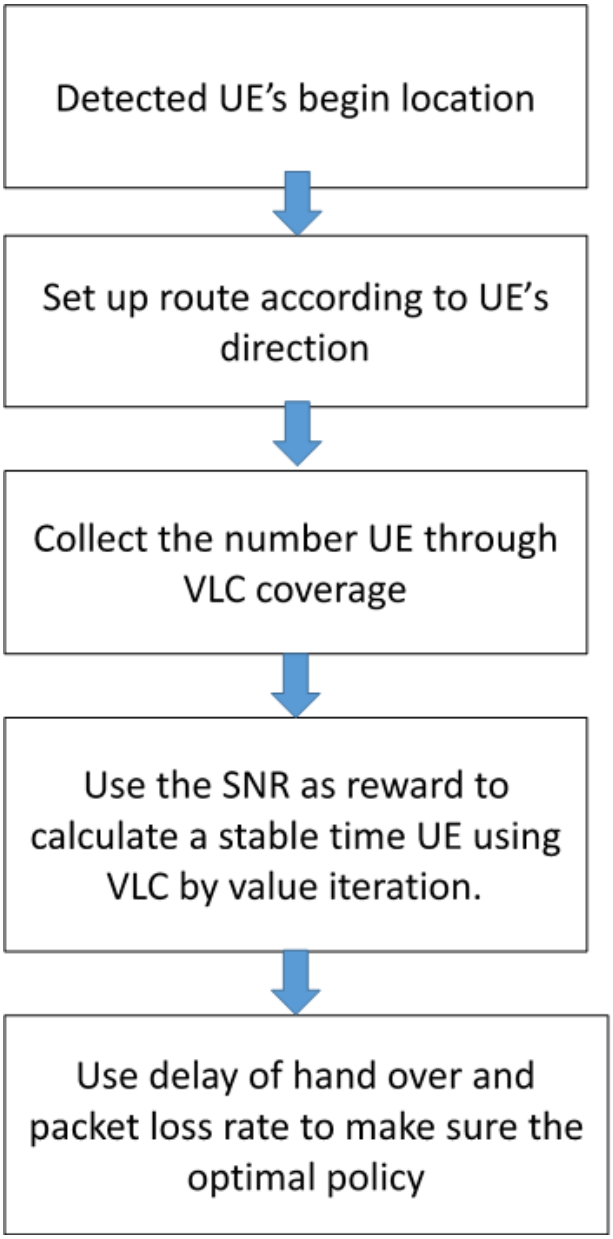
VHO model



As figure shown UE will handover depends on the RSS and SNR. If RF's SNR is better than VLC, UE will handover to RF (as WiFi) vice versa. As discussed in section 2 I assume UE in the room will only moving in straight line, according to discussed section 3, the MDP will be set up in this situation through the time UE using VLC and RF, the probability UE handover will be calculate according to the speed access point receiver the packet and the UE using VLC or RF.

Because of MDP is using for discrete time, so I set state as UE depends on UE is using VLC or RF, the whole time UE will moving in the room will be use to describe the whole processing.

The flow chart will be showed fellow


Detected UE's begin location
Set up route according to UE's direction
Collect the number UE through VLC coverage
Use the SNR as reward to calculate a stable time UE using VLC by value iteration.
Use delay of hand over and packet loss rate to make sure the optimal policy

Probability set up

The probability for states is depends on the time
Set λ as the rate access point receive the packet
Set γ as the time UE using RF
Set μ as the time UE using VLC

The probability will be calculate as

$$p = \begin{cases} \dfrac{\lambda}{\lambda+\gamma+\mu} \\ \dfrac{\gamma}{\lambda+\gamma+\mu} \\ \dfrac{\mu}{\lambda+\gamma+\mu} \end{cases}$$

The reward will calculate as

$$g(i,p) = p_{vlc} \times RSS_{vlc} + p_{RF} \times RSS_{RF}$$

Consider about the discretization, if set $T_{totally}$ is totally time
The probability will change to

$$P_{s \to s+1} = \begin{cases} \dfrac{p}{T_{totally}} \times p & s+1 = s \\ \dfrac{p}{T_{totally}} \times p + 1 - \dfrac{p}{T_{totally}} & s+1 \neq s \end{cases}$$

And finally the value iteration will be shown as

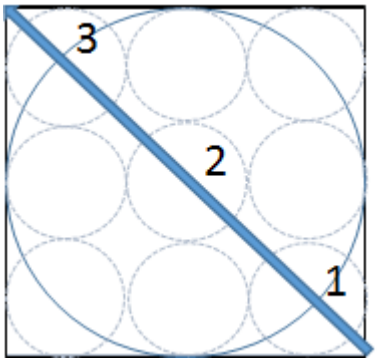
For all s $\in S$
$V_0 = 0$
End for
While $\Delta > \in$ do
For each s $\in S$ do
For each p

$$Q = g(i) + \sum p\, Probability \times gapxopmg;$$

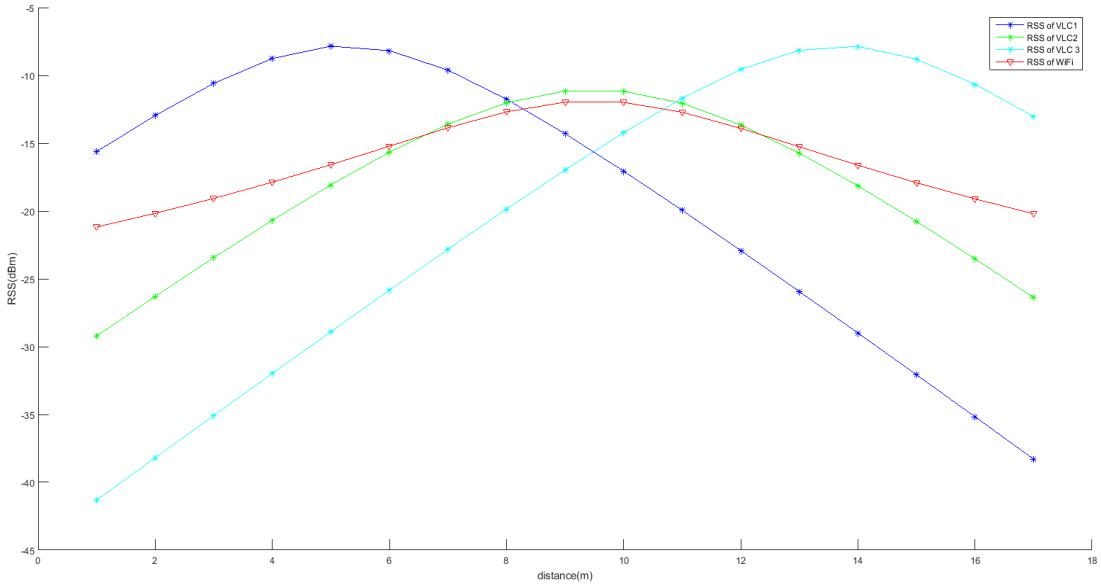
End for
$\Delta = \|V_k - V_{k-1}\|$
End while

If the buffer of access point is full , packet loss will happen so the probability of packet loss will be as
P = $\sum s \in S\, p(b = B)$.

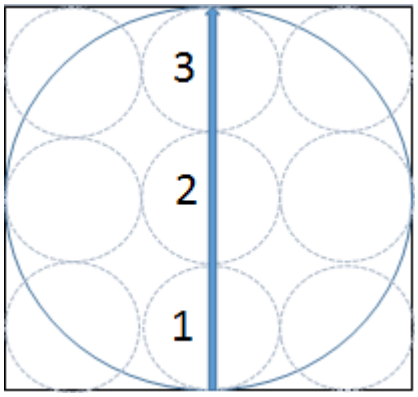
In order to get the better time UE using VLC, service time UE using VLC has been calculated, I will show up some samples here.

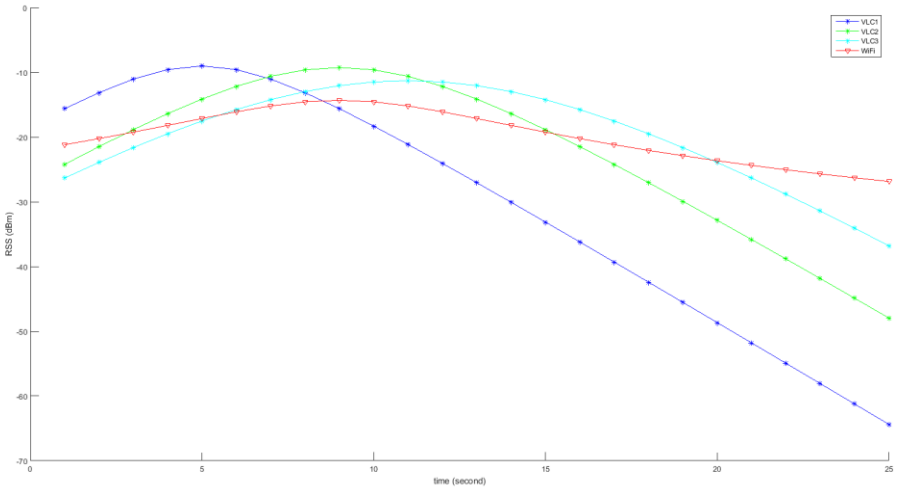


a route UE will go in diagonal through the room.

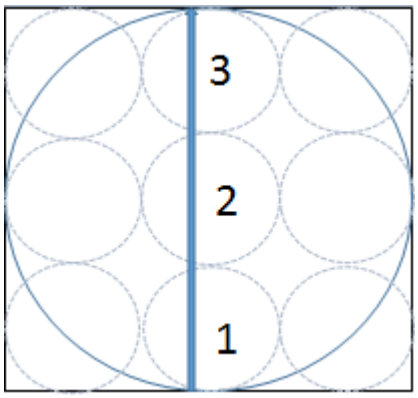


X-axis means the time in second and Y-axis means RSS in dBm, blue line means RSS in VLC 1, cyan line means in VLC 2, and green means RSS of VLC 3.
The time UE using VLC is 5s in this situation.

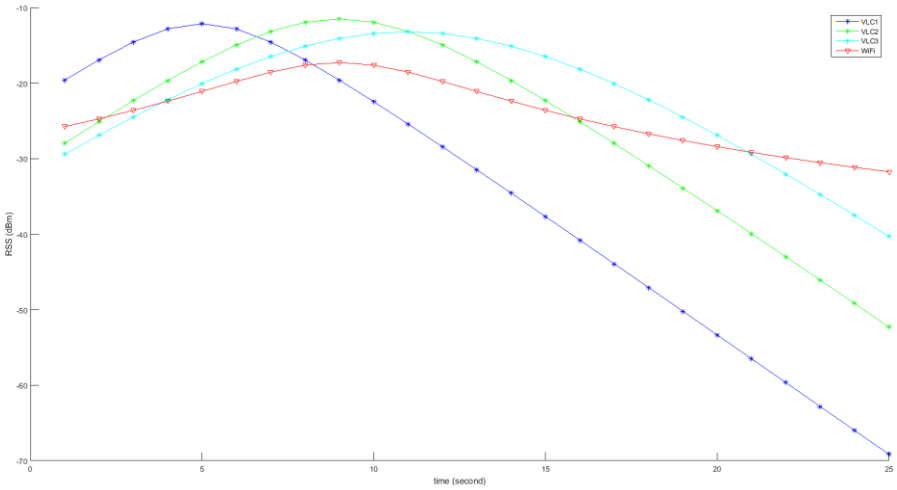




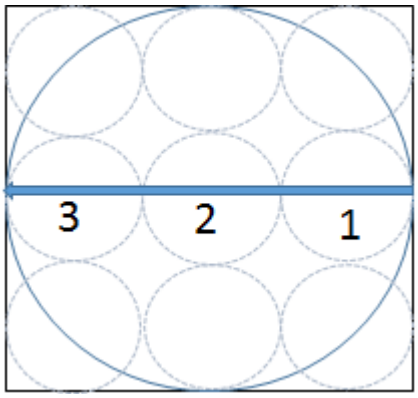
X-axis means the time in second and Y-axis means RSS in dBm, blue line means RSS in VLC 1, cyan line means in VLC 2, and green means RSS of VLC 3.
The time UE using VLC are 5s and 10s



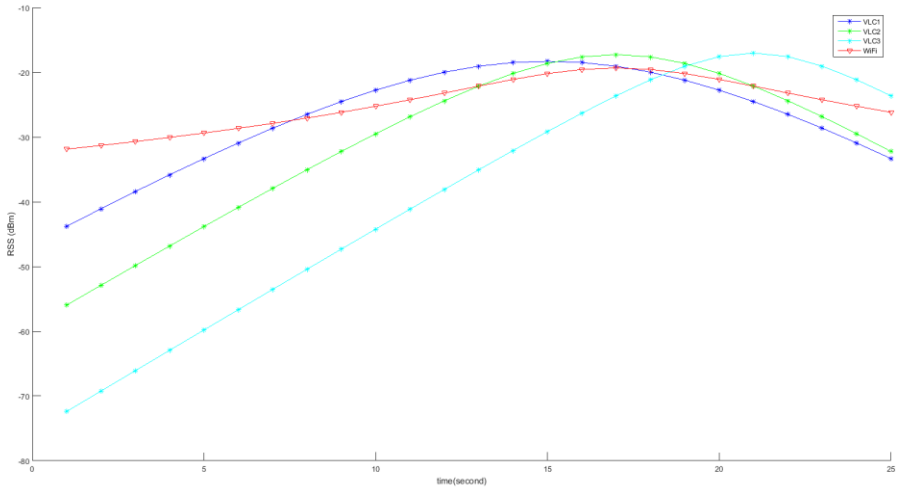
UE will start from (11,0) and stop at (11,24) position and the time will as



The time UE using VLC are 2s, 3s and 7s



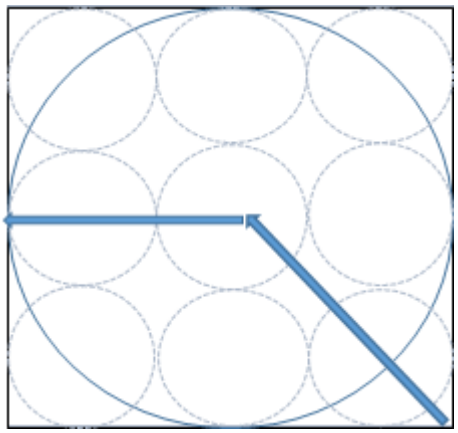
In this route UE will start at position (24,12) and stop at (0,12)



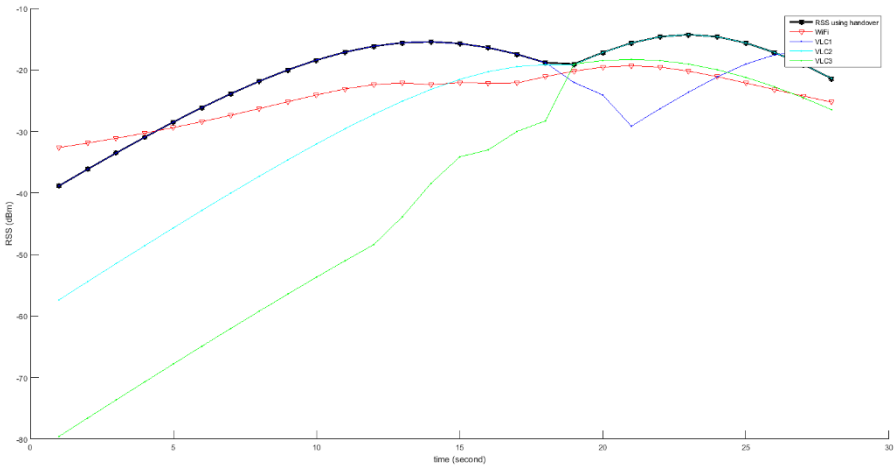
X-axis means the time in second and Y-axis means RSS in dBm, blue line means RSS in VLC 1, cyan line means in VLC 2, and green means RSS of VLC 3.
The time UE using VLC are 3s, 5s and 7s.

5. Result

I simulation different route of UE and get different time UE using VLC, depends on the time I can calculate the packet loss rate.



I done the simulation under UE is moving in this route and result as fellowed



According to the value itervation the time UE using VLC can be setted as 3 second and at the begin although WIFI is better than VLC, UE still didn't done the handover. And the result also showed the RSS is always keep in a high level.

‘

6. Achievement

2017 年 3 月　電子情報通信学会　総会大会　“Study on indoor Optical-RF hybrid Wireless Access Scheme”　**発表予定**

6 References

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