Adaptation to Small Building with Mutual Complement Communication Systems by Wired and Wireless

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Abstract- We have been evaluating "Mutual complement Communication system by Wired and Wireless" for home-network. At this time, we have tried to apply this network to the comparatively small scale business building and we found the very nice result. Compare to home network, we found that many difference in the result of the wired and wireless communication. The bad result is from the reason of multiple transformer and the good result is from the reason of business type cocking system and lighting system. Furthermore, regarding wireless communication, the additional bad result is from the reason of the security reason with small in/out door with metal material.

Keywords: multimedia and communication technology, network, PLC, ZigBee, building.

1 INTRODUCTION

We found 100% network communication result at the Mutual complement Communication system by Wired and Wireless at 3 floor level under 200 m2 home housing[1]. This network system is using 2 different characteristic network; wired and wireless. 2 network are operating simultaneously and get good communication result totally. As wired, we use normal power line in the home. We call it PLC (Power Line Communication). Communication data is on the power line as the carrier signal. As wireless, we use ZigBee (IEEE802.15.4) RF devices [2] [3].

In the home, there are PC internet system, hot water system[4], AV; Audio Video system, home telephone, inter phone and security system as individual devices but not communicated. It is important to have a unified network to work for safety and global environment issue[5]. We aim the solution by using Mutual complement Communication system by Wired and Wireless. The significant point of this communication system is because a network is realizable at low cost. Realization of low cost is because the price fall of a mutual complement network communication terminal (substrate circuit) and attachment become unnecessary. In the logic top, the communication performance has obtained 96.6% in two points[5].In actual old evaluation, the performance of a mutual complement network is 100% (making 3 stories of steel rods into the maximum) of home houses. It is possible to obtain 100% of communication performance by putting in a routing function in such situations. In practical use, although there is no necessity for 100% performance, the work of a communication environmental improvement and attachment it become unnecessary for every house by this high communication performance.

At the relatively small office building, there were power line, internet information line, security system, TV line, telephone, lighting system and other control lines. And furthermore, there are elevator lines[6]. By using these unified network, we can get less additional construction fees in the later. In order to check this idea, we have done Mutual complement Communication system by Wired and Wireless in the relatively small office building. As wired network, when getting electric power through multiple transformer, as we expect, PLC communication is very bad. On the other hand, we found that there are good communication result by 200V business lighting system and business professional cocking system because of 3 line 100V lines. There fore there is less issue of different phase trable in the PLC communication. As wireless, the additional bad result compare to home network is from the reason of the security reason with small in/out door with metal material.

But in order to communicate through multiple transformer, by using wireless, it is important to use Mutual complement Communication system by Wired and Wireless.

2 COMMUCATION CHARACTERISTIC

The In order to guess the communication performance of the mutual complement network by the two communication systems, wired and wireless, an individual communication performance is mersured first [1]. PLC has obstacles by home appliances, such as crosstalk of noise and low impedance. Therefore getting a good communication quality was difficult. In

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recent years, the PLC communication performance is improved by the adoption of spread spectrum technology. But there are still more error correction idea for the noise by the electric white goods appliance [7].

We have done actual communication performance test in multiple houses. More than 40 home electric appliances were operated and we have tested PLC communication performance. Fig.1 is a result of the measurement. The X-axis shows Packet Error Rate(PER), then 0% will be the best and error is 0%. The Y-axis expresses the frequency distribution of all communication courses with %.0%of PER is 70% of frequency distribution from Fig.2.and 100% of PER is 20% of frequency distribution.

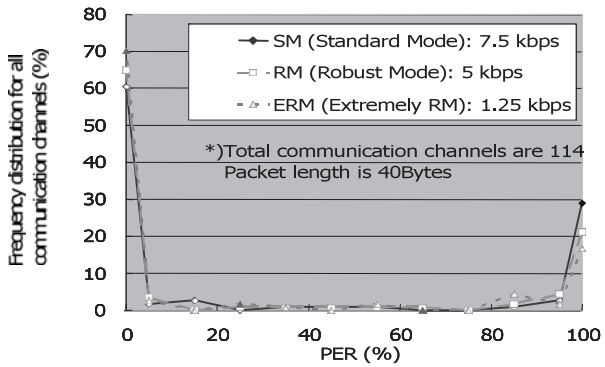

Fig.1. Testing result of PLC (100kHz–400kHz) in typical Japanese home

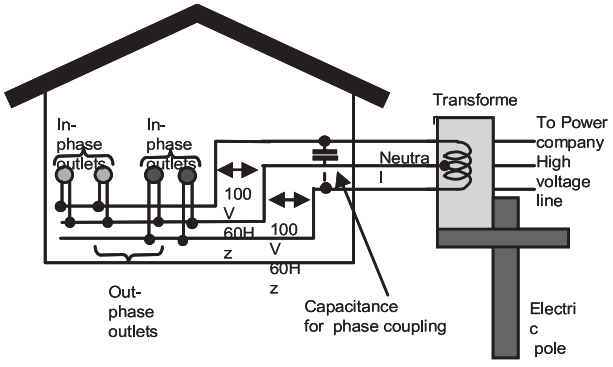

Fig.2. Power line of Normal home

IEEE802.15.4 currently called Zigbee by one of the WPAN (Wireless personal area network) plans as radio is used. This has the performance of a low rate (20Kbps or 250K bps) by low power consumption. Measured value is Fig.3 about the communication performance in the ordinary homes of this Zigbee. The electric field intensity of distance and an electric wave is shown. In prospect distance (open air), electric field intensity is decreased as it separates from near an output antenna so that naturally. In particular, on the second floor, PER showed 40% and a very large value from the first floor in the house of ferro-concrete. Moreover, on the third floor, PER shows 70% and a still larger value from the first floor, and communication performance gets still worse.

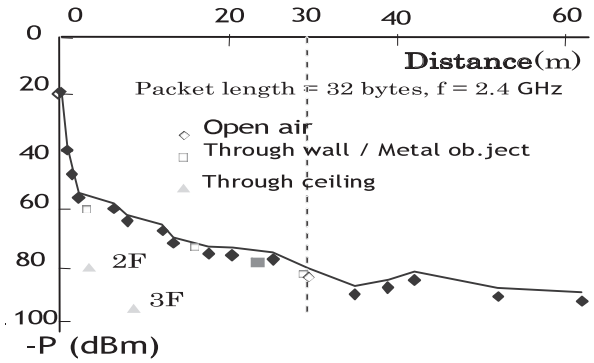

Fig.3. Distance vs electric(dBm)

3 MUTUAL COMPLEMENT NETWORK OF WIRED AND WIRELESS

The preceding clause showed the characteristic of the cable communications PLC and the wireless communications Zigbee. It is difficult to carry out to indoor network completeness with one of communication methods. PLC has a problem of single phase 3 line electric supply, and it has bad communication performance between the electric sockets between unusual appearances. Moreover, even if it puts in a signal coupling instrument between unusual appearances, it does not become sufficient performance improvement.

Although it is satisfactory in the space which Zigbee can keep seeing, it is weak with the obstacle which interrupts a field of view. Then, the communication performance over a floor worsens like the first floor and the second floor. Since the characteristic of these two communication methods is generated according to respectively independent conditions, It is thought that it is mutually suppliable, and also in order to use enough the mutual complement function of a cable and radio to guess the communication performance when using two communication methods simultaneously below, these portions need to consist of unified semiconductors and modules. The valuation basis of the communication quality in network modeling is defined. It is the right data (truth). The data (truth?) which may be right, and the data (imitation) which is not right are classified, and when continuation transmission of the packet data of 40 bytes of both sides is carried out 10 times, the truth criterion of judgment of the data by the side of reception is shown in Table.1.

Table.1. Truth table of reception data.

Classification of reliable	Judgment conditions	Symbol
The truth data	The same data in received in the Truth condition two times successively.	Truth
Possibly the truth data	The Truth data in received two times, but not successively.	Truth?
The false data	Except the above	False

Note: At Fig.1,

As for the frequency of Fig.1, Truth, Truth?, and False is 70%, 10%, and 20%. On the other hand, in the case of radio, it was assumed that the phenomenon between node nodes happened by the same establishment using a typical PER value on each six stories. When it is considered, respectively that PER(s) between a same story and contiguity story and the first floor and the third floor are 2%, 50%, and 70%, the number of phenomena of each conditions is expressed with a figure 8 left-hand-side part, and, as for the frequency by weighted average, 'Truth' 82%, 'Truth?' 14%, and 'False' 4% are obtained. The communication quality at the time of a cable and radio combined use is shown in Table.2. A cable and radio independent communication quality will acquire 96% of value, if Wired's Truth (70%) and Wireless's Truth (82%) improve to 94.6% and 'Truth ?' times 'Truth?' is 'Truth' (1.4%).

Table.2. The Communication quality in % when the wired and wireless communication media are used simultaneously.

		Wireless		
		Truth 82	Truth? 14	FALSE 4
Wired	Truth 70	57.4	9.8	2.8
	Truth? 10	8.2	1.4	0.4
	FALSE 20	16.4	2.8	0.8

Next, the actual proof experiment of the mutual complement network system of a cable and radio was conducted in the dwelling in 3 stories of Ichinohe [8]. Actual proof examination results are all the combination of the first floor to the third floor, as shown in Table.3, and 100% of rate of a data-communications success was obtained.

Table.3. The house of an evaluation experiment. This unit is % display

		Overall success rate			Wired single success rate			Wireless single success rate		
		Floor of reception								
		1F	2F	3F	1F	2F	3F	1F	2F	3F
Floor of transmission	1F	100%	100%	100%	98%	80%	74%	100%	83%	55%
	2F	100%	100%	100%	82%	81%	75%	81%	87%	84%
	3F	100%	100%	100%	75%	76%	76%	60%	83%	93%

It was 86.7%, when the cable independent strike rate was averaged and the radio independent strike rate was averaged 71.1%. In a cable independent, the same story is also presumed to be what a strike rate has about 70% or less of combination, and time, and depends on the difference in phase of the power line to which electricity is supplied, and is in agreement with Fig.4 of the power distribution situation of each story which actually checked.

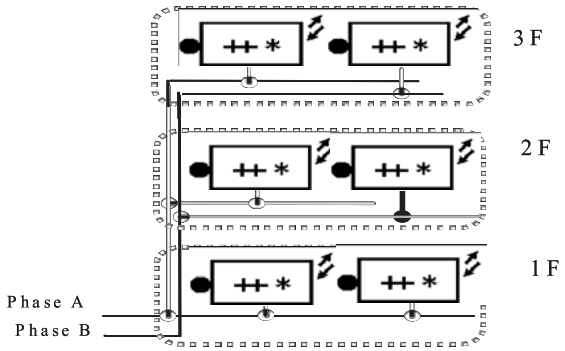

Fig.4. An actual check of the power distribution condition.

In the case of wireless communications, in the case of the same story, it is a strike rate of 100%, and when the second floor is different about 90%, whenever the strike rate of about 60% and a story increase in the case of a contiguity story, range worsens. A communication error performs the supplement at the time of generating at the time of cable independent communication or radio independent communication. Since the error ratio as a mutual complement network is a cable- communications error ratio x wireless-communications error ratio. If it is searched for from the independent strike rate of Table.3. Table.4 is obtained.

Table.4. Assumed success rate between Unit Cells

Floor of transmission \ Floor of reception	1F	2F	3F
1F	100%	97%	88%
2F	97%	98%	96%
3F	90%	96%	99%

If the strike rate of Table.4 is averaged, it becomes 95.7% and is mostly in agreement with 96% of the value of a simulation. In this experiment, since either was communicated by the communication for two points, although it is 95.7%, with a calculated value, an actual measurement becomes 100%, as shown in Table.3.

Although the communication performances of the cable in a home and radio which we have generally got were 70% and 82%, as a result of performing the communication quality assessment of the mutual complement network system of a cable and radio in the dwelling in 3 stories of Ichinohe, the communication strike rate of 100% was acquired as mentioned above, without coping with communication environment in any way. As an average, the strike rate of 95.5 is expectable. A possibility of obtaining an effective network was found out without having improved communication environment in any way to a home or the comparatively small space about a home. I think that 96% of communication quality can be obtained by how to carry out the mutual complement of radio and the cable. Furthermore, in order to measure improvement in communication performance, when the communication for two points was improper, how to go via some relay nodes was examined. The case where each node reached with the first floor, the second floor, and the third floor, and attaches every one a total of six nodes to two phases of a power supply as shown in Fig.5is examined.

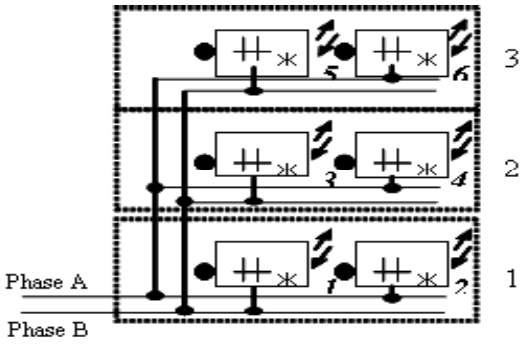

Fig.5. Routing node example at three-story house

The propriety of communication between each node is shown in Table.5. In the case of wred,when was same phase , it thought that communication was possible, and when it was different phase , impossible. In the case of wireless,when was the same floor,it thought that communication was possible,and when it was different floor impossible.

When not knowing the number of stories and the same phase and the the diffrent phase of a power supply in which the node of a communication place exists according to this condition, as shown in Table.6 and Fig.6,

the number of times of communication per route is distributed from 1 time to 6 times. Moreover, when the number of stories is found and it cannot communicate at once, the number of times of communication per route can be reduced even to a maximum of 3 times by using the algorithm of going via the node of the same story as a dispatch node or the purpose node. Furthermore, when the same phase or the different phase phase a power supply is known, it becomes the two or less number of times of communication per route between all nodes.

Table.5. Communication between two nodes
P : Success by PLC communication
Z : Success by 802.15.4 communication
X : Communication impossible

Sending node No. \ Receiving node No.	1	2	3	4	5	6
1	—	Z	P	x	P	x
2	Z	—	x	P	x	P
3	P	x	—	Z	P	x
4	x	P	Z	—	x	P
5	P	x	P	x	—	Z
6	x	P	x	P	Z	—

Table.6. Comparison of communications per route when the floor number and power supply phase are known.

Floor list	Unknown	Known	Known
Same/different phase list	(unknown)	(unknown)	(known)
Number of routing times	Number of communications per route		
1 time	18	18	18
2 times	—	—	12
3 times	24	24	—
4 times	48	—	—
5 times	36	—	—
6 times	24	—	—

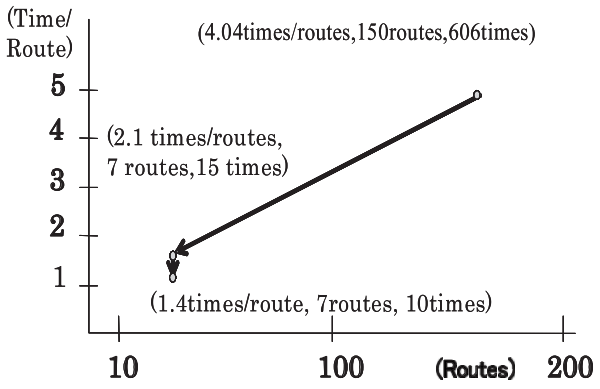

Fig.6. Number-of-times reduction of routing

4 COMMUNICATION PREFORMANCE EVALUATION AT A SMALL BUILDING

We have done the communication performance test by wired and wireless mutual complement network at 3 type different relative small building. We call them A building, B and C. A is the office building with 1586m2 floor, B is the university building with 5365m2 floor and C is the graduate school building with 1920m2 floor.

The measurement result of the each building are showed at Table.7,Fig.6.The equipment list of the building which affects to wired PLC communication and wireless ZigBee is showed on Table.9.

Same situation of each building is that 200V electric fluorescent lamps are equipped, then PLC communication result is better at different phase power line. A is the relatively small building with only one transformer. Normally PLC communication is worse because of multiple transformer, so PLC communication was good because of 1 transformer. Also, in A building , there is 1 restaurant with 200V professional cocking systems, then it was easy for different phase communication because of 200V system connects to 200V; two phase. Success rate of PLC was 98%. On the other hand, the success rate of wireless ZigBee was 8.4%, very bad. Why so bad was because of small windows which can offer open space to ZigBee RF signal and because of metal material wall and door. It was impossible between walls and doors. Even at stairways with open air, it also showed bad success rate because of metal materials stairways.

At B building, PLC only communication success rate was 74.4%. The different phase communication with PLC was OK even at different floors with 200V systems. Between different transformers, as we expected before, the PLC communication was impossible. ZigBee only communication rate was 60.3%. In B Building, there was wide open space at stairways and hallway, so it was easy for wireless ZigBee communication. Especially at stairways space, it was OK for ZigBee communication even between 2 floors difference.

In C building, close to B building case, PLC success rate was 61%. There were multiple transformers in C Building, so as expected before, it was impossible for PLC communication between the transformers. Also relatively small building has 1 electrical box (distribution panel) in 1 floor. In this building, different from B building, the PLC communication between different distribution panel was impossible.

Therefore the PLC communication in the same floor with different phase was OK, but the communication between different floor was impossible. Total ZigBee communication rates was 48.8%. The tendency was equal to B building, but little bit worse communication rate because of narrow open area than B building. Regarding B and C building, the efficiency of the Mutual complement Communication system by Wired and Wireless was proved. Both buildings have the difficult position where PLC and ZigBee communication was impossible. Even if one communication is interruption, aid is given by other the communications of one.

At A building, the efficiency of Mutual complement Communication system by Wired and Wireless was low, because PLC can communicate almost all places.

Table.7. Mutual complement network performance evaluation of each building

Building name	Summary	Number of Tr	Communication performance					
			PLC		Zigbee			MCN
			Tr		Same room	Same floor	Dif floor	
			Com	Dif				
A	1586.4m^2 B1～7F	1	a	-	a	d	x	b
B	5365m^2 B1～4F	3	b	x	a	c	c	a
C	1920m^2 B1～4F	3	c	x	a	c	c	a

Note: a: 95% or more
b: 90% or more
c: 70% or more
d: 70% or less
Tr: Transform(s)
Com: Common
Dif: Different
-: It does not exist.
MCN: Mutual Complement Communication Network

Table.8. The communication performance in each building of PLC and Zigbee (%)

	PLC	Zigbee
A	98	11.1
B	74.4	55.8
C	52	43.8

Table.9.The factor which determines the communication performance of each building

	PLC	Zigbee
A	performance good. In existence of 200v fluorescence lighting and cooking apparatus	Only the inside of the room can be communicated. a small window, a metaled door, the wall of a steel rod.
B	Except for between transformers, it is performance good.	Good on stairs. Good to a length of 30m in a passage.
C	Except for between transformers, it is performance good.	Good on stairs. Good to a length of 30m in a passage.

4.1 PLC characteristic in the relatively small building

Normal power wiring example in the relatively small building is showed as Fig.9 based on the one of C building. 6600V, high voltage from power station was transformed to 100V/200V with R/T/N phases by the transformer and distributed to each home's distribution panel.

From distribution panel, 100V was distributed to each consent (power outlet) by the connection of RN and NT separate from 200V. The PLC communication on different Phase during 100V appliances must become back to transformer. In the transformer, the quality of the PLC communication between different phases becomes worse because of noise and electrical transform. When using 200V appliances, PLC communication can be sent to the destination point without backing to the transformer.

The PLC communication signal is on R and T phase of AC line, if R and T was tied by 200V appliances, the communication between different phases becomes easy because of the R & T bridge. At the relative small building where we have done this experiment test, each building was using many 200V appliances. Therefore the improvement of PLC communication performance was done between the different phase where PLC does not like.

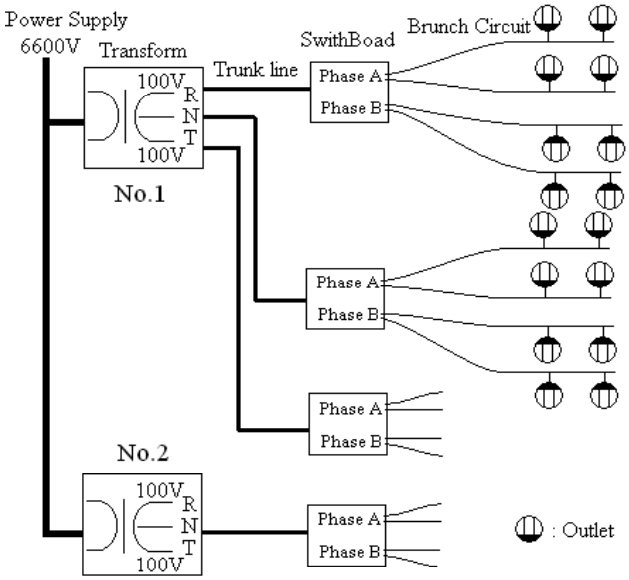

Fig.7 The power line routing diagram in C building.

Note: There are 3 transformers, but 1 is for motor power duty, so we have not described the one. Main Power line has 3 phases; R,N and T phase. These are separated to each power outlets through power distribution panel.
Phase A: R-N Phase B: N-T

The experiment test result by wired PLC line is showed on Table.10. It shows the result of C building. C building has 3 transformer. The transformer for normal appliances are 2 and showed as Fig.7. This transformer has 3 main power lines. No.1 transformer is for B1~2F and No.2 transformer is for 3F, 4F, computer room, server room. Then main power line of each transformer comes to each power outlet in the room through each floor's power panels. Basically each floor uses 1 main power line.

At our experiment, we got very nice testing result (means PER=0%) when same main power line, that is same floor even at different phases. This nice result is from the following reason; 200V fluorescent lamp acts as the bridge between R and T phase which contains PLC signals, PLC signal does not need to come back to transformer and PLC signal reaches to different phase line directly not through transformer.

But regarding the PLC communication between different floors with different main power lines, PER becomes up (worse) and it was impossible to make PLC communications. The reason of the worse result is as follows; when communication to different main power line, the PLC signal comes to outside transformer once , also gets many noise and may attenuate PLC signal power.

It was impossible to make PLC communications through different transformer. The theory of transfor-

mer is as follows; primary coil gets magnetic flux at the metal core by AC current and secondary coil gets electromotive force. In order to get PLC communication, actual connection of wire is necessary. Primary coil and secondary coil is not connected, so PLC communication must not happen. It is impossible for PLC communication during transformer.

Table.10. PLC communication success rate (%)

Transform	Floor						
No.1	PC	100					
	4F	50	100				
	3F	-	18	100			
No.2	2F	-	-	0	100		
	1F	-	-	-	4	100	
	B1	-	-	-	-	0	100
		PC	4F	3F	2F	1F	B1
		No.2			No.1		

Note: PC: Computer room / Server room
-: it dose not evaluate

In order to show each route communication performance easily, we defined load level number as Table.11. It is trial to show PLC communication characteristic by load level number.

The decision items to decide load level are 4 items; transformer, main power lines, phase and brunch circuit as Fig.9. Load level 1 shows lowest load on the communication route and highest communication success rate when transmit and reception power outlets are on the same power lines with same brunch circuit. According to different brunch circuit, different phase, different main power line and different transformer, load level becomes higher and communication becomes more difficult.

Actual experiment result and load level at C building are shown as Fig.8. Black dot shows actual experiment value and black line shows load level according to the black dots. According as load level becomes high, PLC communication performance becomes worse. At this experiment, when same main power line, PLC communication success rate was 100%. This was the result because of 200V appliances which can enable the PLC communication between different phase which PLC does not like. There is difference between black dot and line of Level4 and level5, but black line may be expected to show theoretical value because the PLC communication between different phase is worse than same phase.

According to above result, at the relatively small building with many 200V appliances, when same main power line, PLC will be effective communication method regardless of phase difference before level 3.

Table.11. The definition of the communication load level in PLC

Load Level	Transform	Trunk line	Phase	Brunch Circuit
1	Y	Y	Y	Y
2	Y	Y	Y	N
3	Y	Y	N	—
4	Y	N	Y	—
5	Y	N	N	—
6	N	—	—	—

Note: Quantification is defined for the load of the course from the wall socket to the target wall socket which transmits. Reference figure fig7
Y is in the same wiring and is yes.
N is in different wiring and is NO

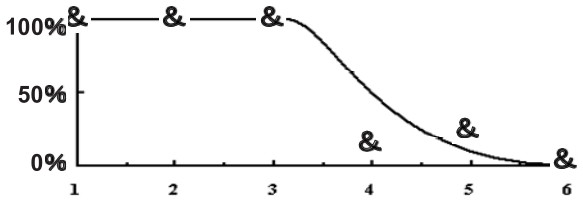

Fig.8. Relation between the communication load level and a communication performance.

Note: "&" mark is an actual measurement.
A communication performance falls in proportion to the communication load level

The distribution of PER at small building is shown as Fig.9. The total routes of this PLC experiment in these 3 buildings were 139 routes. At small building, the frequency distribution was 64.7% with 0% error, 26.6% with 100% error and 8.7% with 0~100% error, then these data was almost close to normal house case.

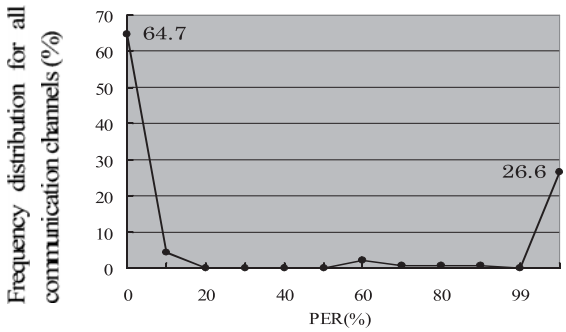

Fig.9. The PLC experiment result at 3 small buildings with total 139 case.

We compare the PER of Fig.1 at normal houses to the PER of Fig.9. at small buildings, then we show the result at Table. 12. At small buildings, PER100% number is 3.4 points lower than the PER100% of normal house and PER 0% number is 5 points higher. This means that PLC communication performance at small building is better than the one at normal houses. The reason of this better performance is as follows; many 200V appliances at small building will give good bridge function to different phase communication.

Table.12. The average value comparison of PER at home network and small building.

PER	Home	Building	Diff
100	30	26.6	3.4
0	60	65	5

Note: Compare to home network, PLC performance in small building is better than home network. (%). Diff: Difference

4.2 ZigBee performance at small bulding

Regarding RF ZigBee communication, we have done this experiment with 500 packets with 20 sec interval.

A building locates in city center area and has relative small windows and narrow metal stairs. Because of iron metal door, ZigBee can not make communication well. The communication success rate was only 8.4%. B and C building are university building with open wide air. The RF ZigBee rate of B building was 603% and C was 48.6%. Near by stairs, the ZigBee communication between floors was OK and we got nice RF communication performance. The actual experiment value of RF communication in B building was showed by Fig.10.

At the university building with wide open air, ZigBee can communicate even between 2 floors with high communication success rates. ZigBee communication performance in small buildings is affected much by wall density and material

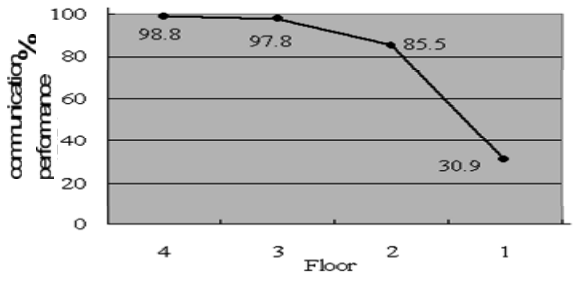

Fig.10. The ZigBee communication success rate from 4th floor to other floors at B building. Near stair place, the communication perforance is still OK even between 2 floors distance.

4.3 The performance of Mutual complement Communication system by Wired and Wireless

After actual experiment, we found that Mutual complement Communication system by Wired and Wireless originally for home network is still effective for relatively small building.

As A building with only 1 transformer shows, wired PLC communication can be effective highly. But it is difficult for the buildings with multiple transformers to have good PLC communications under multiple transformer and main power lines. Especially, through different transformer, it was impossible to have PLC communication.

From this experiment, Regarding PLC communication, in order to solve multiple transformer problems and main power line problems, ZigBee communication at the open air and stair place must be effective and Mutual complement Communication system by Wired and Wireless shown on Table.7 must be effective at relative small buildings. Moreover, as shown in Fig.11, compared with the home, it has checked that the variation in a communication performance was also large.

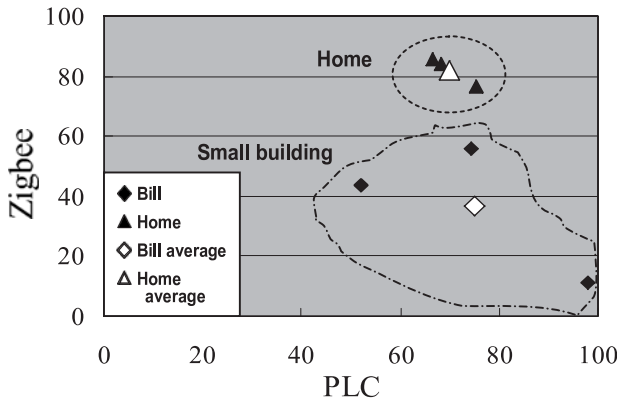

Fig.11 The difference in the communication (PLC and Zigbee) performance of a small building and a home.A small building has the large distribution of a communication performance.

5 CONCLUSION

We have done actual experiment in order to adapt Mutual complement Communication system by Wired and Wireless originally for home network to 3 small buildings. As the result, we found that Mutual complement Communication system by Wired and Wireless originally is still effective for relatively small building without any additional modification about communication environment. We also found that in small building there are more difference in communication performance by wired and wireless compare to

home network. In wired, multiple transformers will affect to communication performance.

On the other hand, 200V business professional kitchen system and business fluorescent lamp will give good affect to wired PLC communication. As for ZigBee communication, from the security reason, small builfding's door and windows are small and metarised, therefore the ZigBee communication will get worse performance . From above result, the performance of mutual complement Communication system by Wired and Wireless in buldings is different from the one of normal home as following 2 two items;

The first item as for PLC, it is impossible between multiple transformers to have PLC communication. On the other hand, 200V appliances as "bridge function" will help PLC high performance communication between each floor's distribution panels and different phase.

The 2nd item ,the ZigBee communication area is relative narrow. Only within room distance and same floor level with good condition. Also at stair portion and open air, we can expect higher communication performance, almost equal to 100%.

Regarding the adaptation Mutual complement Communication system by Wired and Wireless to small building, from our actual experiment, the PLC communication with bad performance by multiple transformer and main power lines must be gated by ZigBee communication. In normal home network, we do not need to consider this issue. But in small buildings, we must consider this gating. Regarding gating position, there must be open air position or stair position in the bulding. We must put the gate function to bridge PLC and ZigBee at power outlet position for network communication at each floor.

In normal home network, we do not need to consider any additional equipment regarding Mutual complement Communication system by Wired and Wireless, but in the building case, we must put special node outlet with PLC and ZigBee function. At this report, we have determined communication load level regarding PLC communication, furthermore in order that this value becomes more and more, we must pay attention more about PLC communication. Also regarding ZigBee, we would like to determine ZigBee communication load level from now on.

At relative small buildings, there are 4 or 5 routes like power lines, internet lines, security lines, TV lines, telephone lines and so on. It is important to monitor these lines and to integrate these lines, therefore we believe that Mutual complement Communication system by Wired and Wireless must be beneficial for these integration.

By this study, the important characteristic at the time of being adapted for a home in this mutual complement network was able to be known. When floor area and a class increase, as for Zig-bee of wireless communications, a communication performance falls remarkably by becoming a small building, so that more clearly than Fig.11. However, PLC of wired communications can expect improvement in the communication performance by 200v apparatus, if the fall of the characteristic by the increase in a transformer is removed. By these, evaluation of this mutual complement network to a small building can be understood that an effective thing is shown, if addition of the transformer of supply electric power is removed also in a still larger dwelling to application at home.

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