Multihop Wireless Controlled Sensor and Actuator Network for Cable Installation System

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Abstract - A Long and heavy cable should be carried out the installation under the construction of plant. The current cable installation system drives the cables to relax the physical stress of workers, although. That system cannot work to pull the long and chained cable sequentially at the timing of tension triggered to the cable head by worker. We propose the multihop wireless controlled system that works to push the cable at the timing of instruction packets delivered by tension applied. This paper explains the adoption of multihop wireless controlled sensor and actuator network into the cable installation system.

Keywords - cable installation; wireless network; multihop communication; sensor; actuator

I. INTRODUCTION

Power cables and communication cables etc. used in electrical equipment such as various types of pants, buildings, factories laid on the cable tray along the ceilings and walls. These cables are in the 1,000 m long and would be heavy, thus, total line work puts many workers on the layer route and cheer each other for the cable installation.

The current cable installation system reduce the work load by cable driven from the power of assisted ball roller instead of human power of workers [1], [2]. Assist ball rolling using machine-rolled line work, workers insert the cable head into the ball roller between motorized winder, then workers rolled applying tensile by pulling power. This tension is detected strain sensor with the assist ball roller and operate the motor rotate the balls during a constant time, so that nestled between the balls rotated off. Such assist ball roller is placed regular intervals on a rack, the cable is rolled by repeat of tension applied, so that a long and heavy cable rolled in the buildings of the plant. However, this line work has a progress on ahead, total cable gripped with the winders on the drum side grows load against the tension applied to the cable head, so that the assisted ball roller will be unable to operate to drive the cables by pulling power. In addition, total cable should be rolled extension to where lines such as turn of left and right and up and down. More at the top of the cable, strong tension applied to potentially cause damage to cables. Therefore, if the applied tension will no longer rotate the ball, the cable sandwiched with ball winder will be lifted down and manual operation by rolling work requires temporary, so that degrades the efficiency. Figure 1 shows the pictures of cable drum and assisted ball roller.

Monitoring the status of rolling and control the on/off of cable rolling with each assisted ball roller from central control unit by worker have been proposed. However, it is necessary to prepare the equivalent length of control cables for power and LAN, and the advance training of the PC operation of control unit to the workers [3]. At long distances, there are ways to reduce the cable weight using PLC (Power Line Communications) control cable, although. There would be a lack of noise performance and response time [4].

We propose the multihop wireless controlled system to the assisted ball roller without the wire line controlled equipment for the total working smoothly and efficiently with small number of workers. This paper is rolled the adoption of multihop wireless controlled sensor and actuator network into the cable installation system, real space of the line positions assigned to the wireless network address due to the progress adaptively and the description of a line instruction packet by multihop communication.

Figure 1. Cable Drum and Assisted Ball Roller

II. RELATED WORK

Sensor networks using multihop communication focus the development of protocol for the congestion avoidance by route controlling toward the sink side [5], [6] and the power saving due to intermittent operation of the terminal [7], [8]. And the studies have been made as manly. Also, in general, when controlling the target device from sensor data collection, the monitoring of the state of the target device and the control instruction such as sensing (input from the real world) and actuation (output to the real world) is performed by two-way communication.

In the case of control of industrial equipment, in FA (Factory Automation), wireless communication is desired in terms of space, cost, and the like in existing wired cables. For this purpose, time constraints and real-time

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characteristics are required as well as in the wired case, and research on the physical layer and MAC layer specialized for control is in progress [9], [10]. Transmission equalization using downlink equalization information between the master and the slave is intended to reduce preambles in the uplink and improve frame utilization efficiency. Here, one-to-one or one-to-N direct communication is performed with respect to real space input / output (master and slave) in terms of time constraints.

In addition, in the surveillance system for regional children, research is being conducted on a protocol that performs fixed-length waiting time and duplication suppression in order to make the packet loss rate equal to or less than a specified value [11], [12]. Information on the position and passage transmitted from a child's wireless device (child device) is sent to the server side via an Ad-Hoc wireless network based on a repeater network, and a guardian accesses a Web page to access the map. You can check the position of the children displayed on the. Here, with respect to the information space (server) obtained from the real space (children etc.) using multi-hop communication, a person judges the state and the relevant authorities take action.

In addition, in application to wireless sensor networks in the agricultural field, construction of a system that is low in cost, capable of long-term operation with power saving, and highly resistant to animals and pests as well as environmental conditions Research is being carried out towards [13], [14]. It collects complex information such as weather conditions, changes in soil, and detailed images of plant surfaces in combination with wired LANs and wireless mesh networks, and automatically adjusts watering, temperature and lighting, etc. Here, multi-hop communication is used in both directions of collecting sensor data in real space (farm) and controlling real space (growing of agricultural products) [15]. From the sensor data collection to the control instruction of the target device, direct communication is performed when the time constraint is relatively severe, and multi-hop communication is applied when it is relatively loose.

The author applies multi-hop communication to a path to be actuated (output to the real world) which is control to a cable installation system.

When controlling a device using multi-hop communication, there is a concern that the operation confirmation may become difficult in practice because the target device is physically located at a long distance from the delay time due to the multi-hop communication.

Therefore, multi-hop communication is applied to cable installation work in the case of a sequential control type in which the operation is performed while confirming responses including the delay time, and as a feedback type case where final operation confirmation can be performed. When the strain sensor attached to the assisted ball roller detects tension application by the worker, the wireless device equipped with the assisted ball roller closest to the cable front side wirelessly transferred by multihop communication as a cable extension instruction packet to wireless device equipped with the assisted ball roller closet to the cable drum side, delivery, sequentially, that's extended cable instruction packet is delivered by multihop communication from the wireless device equipped with assisted ball roller on the cable drum side to the wireless device equipped with assisted ball roller on the cable front side to drive the cable, whereby the worker who applied tension takes the final position of the extended cable. The operation can be confirmed.

III. PROPOSED METHOD

A. Basic Principle

Basically, we will stop the physical tension transmission method by pulling the current cable, wirelessly transmit the tension application information, and propose a method of pushing the cable from the cable drum side to cable front side. At that time, if the tension application information does not reach directly, relay on the way of the wireless device equipped with the assisted ball roller on the way to reach by multi-hop communication. Figure 2 shows the image of the operation by multihop wireless controlled cable installation system

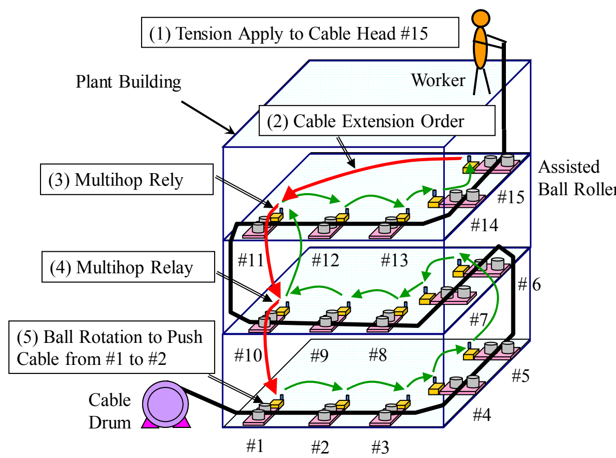


Figure 2. Proposed Operation of Cable Installation

B. Real Position Assigned to Wireless Network

After the wireless devices equipped with assisted ball rollers are positioned, they are not moved until the cable installation operation is finished, and they are in a static arrangement, hence, a table driven (Proactive) [16] wireless network is constructed. Therefore, each wireless device exchanges route information periodically in hello packets (BC: broadcast), and shares route information with all wireless devices in the wireless network. At this time, a wireless network is constructed with a wireless device specific address (hereinafter referred to as "mac ID") equivalent to a so-called MAC (Medium Access Control) address. Actually, as mac ID, set by DIP switch and set so as not to overlap. Workers who perform the cable extension work randomly place the assisted ball rollers along a straight line or a bent line regardless of the address. In the wireless network constructed in this way, the routing table of each wireless device uses mac ID to indicate whether it can directly communicate with another wireless devices by radio wave propagation or perform multihop communication.

On the other hand, in the cable installation operation, since the cable is pulled out from the drum and inserted into the assisted ball roller and driven, the wireless device order address according to the physical order of the assisted ball roller arranged from the drum side to the cable head (Hereafter, it is called "extension ID") is required. Figure 3 shows the constitution of mac ID and Extension ID in the IEEE 802.14.5(/ZigBee) frame.

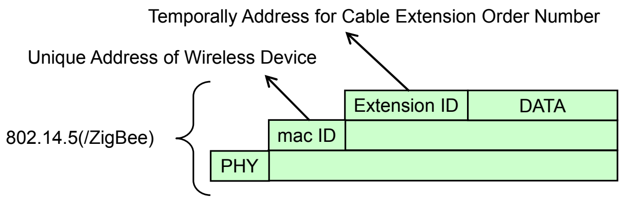


Figure 3. mac ID & Extension ID

Therefore, immediately after tension application, after the wireless network is established, the wireless device sends out each hello packet to which an extension ID corresponding to the mac ID is added for notification. This information is received by an adjacent wireless device equipped with assisted ball roller, and its information is periodically inserted into hello packets and broadcasted to all the wireless devices by broadcasting. As a result, it is possible for all wireless devices equipped with assisted ball rollers to know the number of cable extension in which the cable installation operation is progressing. When tension is applied to the assisted ball roller, the current extension ID is incremented by +1 and immediately added to the hello packet to perform broadcasting. Therefore, there is no need for recording and management operations such as mapping between the mac ID and the extension ID of the wireless devices equipped with assisted ball roller. The tension applied wireless device sends a push packet (UC: unicast) instructing cable extension to # 1 of extension ID, and from # 1 to # 2, # 2 to # 3, # 3 to # 4, # 4 to # 5 and # 5 to # 6 in order. Finally, once the cable instruction packet arrives at the wireless device subjected to tension application, cable extension work by one tension application is finished, and by repeating this, cable extension for a long distance in a building such as a plant is repeated. The scheme described above is shown in Figure 4.

Figure 4 shows the extension ID corresponding to the mac ID when each radio wave of wireless devices reach any of the wireless devices. Likewise, Figure 5 shows a state in which radio waves reach any of the wireless devices like Figure 4, and the number of hops in the routing table is 1, and gate way (gw) and destination (dst) is same wireless devices as shown in Figure 5.

Also, for example, when there are radio wave obstacles or the like between # 6 and # 1, the number of hops in the routing table is 2 when relaying via. # 3 as shown in Figure 6. Thus, cable instruction packet from #6 is delivered to #1 via. #3 as one time relayed multihop communication.

Further, Figure 7 shows a state in which radio waves reach to the next wireless devices, and the numbers of hops in the routing table is incremented +1 per relayed to the destination, and gate way (gw) is the next wireless devices as shown in Figure 6. Thus, cable instruction packet from #6 is delivered to #1 via. #5 and via. 4 and via.3 and via.2 as four times relayed multihop communication.

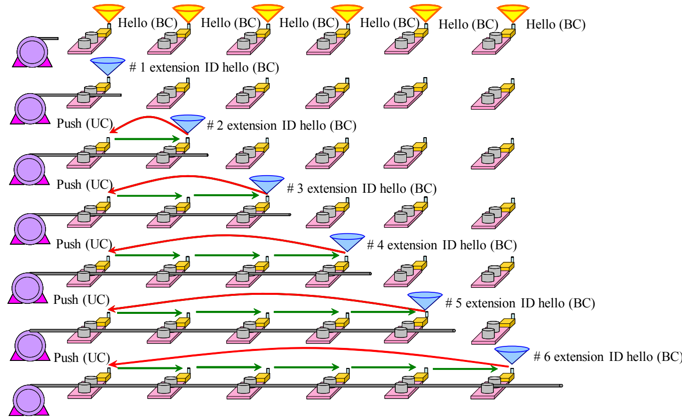
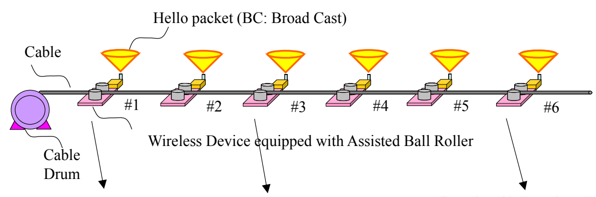


Figure 4. Extension ID corresponding to the mac ID



#1 routing table (extension ID)

org	gw	dst	hop	rssi
#1	#2	#2	1	r21
#1	#3	#3	1	r31
#1	#4	#4	1	r41
#1	#5	#5	1	r51
#1	#6	#6	1	r61

rssi XY (from X to Y)

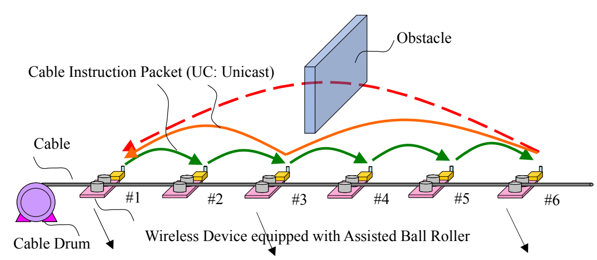
#3 routing table (extension ID)

org	gw	dst	hop	rssi
#3	#2	#2	1	r23
#3	#1	#1	1	r13
#3	#4	#4	1	r43
#3	#5	#5	1	r53
#3	#6	#6	1	r63

#6 routing table (extension ID)

org	gw	dst	hop	rssi
#6	#5	#5	1	r56
#6	#4	#4	1	r46
#6	#3	#3	1	r36
#6	#2	#2	1	r26
#6	#1	#1	1	r16

Figure 5. Routing Table (Direct Communication)



#1 routing table (extension ID)

org	gw	dst	hop	rssi
#1	#2	#2	1	r21
#1	#3	#3	1	r31
#1	#3	#4	2	r31
#1	#3	#5	2	r31
#1	#3	#6	2	r31

rssi XY (from X to Y)

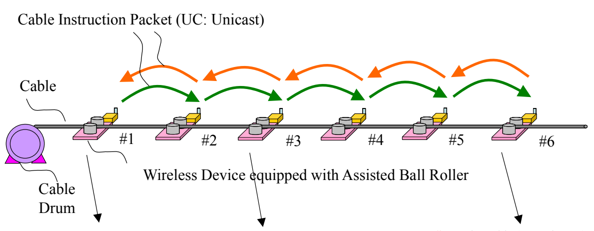
#3 routing table (extension ID)

org	gw	dst	hop	rssi
#3	#2	#2	1	r23
#3	#1	#1	1	r13
#3	#4	#4	1	r43
#3	#5	#5	1	r53
#3	#6	#6	1	r63

#6 routing table (extension ID)

org	gw	dst	hop	rssi
#6	#5	#5	1	r56
#6	#4	#4	1	r46
#6	#3	#3	1	r36
#6	#3	#2	2	r36
#6	#3	#1	2	r36

Figure 6. Routing Table (# 6 to # 1 via. # 3 relayed)



#1 routing table (extension ID)

org	gw	dst	hop	rssi
#1	#2	#2	1	r21
#1	#3	#2	2	r21
#1	#4	#2	3	r21
#1	#5	#2	4	r21
#1	#6	#2	5	r21

rssi XY (from X to Y)

#3 routing table (extension ID)

org	gw	dst	hop	rssi
#3	#2	#2	1	r23
#3	#1	#2	2	r23
#3	#4	#4	1	r43
#3	#5	#4	2	r43
#3	#6	#4	3	r43

#6 routing table (extension ID)

org	gw	dst	hop	rssi
#6	#5	#5	1	r56
#6	#4	#5	2	r56
#6	#3	#5	3	r56
#6	#2	#5	4	r56
#6	#1	#5	5	r56

Figure 7. Routing Table (Multihop Communication)

Depending on the speed at which the worker walks with the cable, tension is applied between the assisted ball rollers several times, and the cable is pushed to extension little by little to make the cable arrive at the adjacent assisted ball roller. The included hello packet will be broadcasted multiple times, and although it does not have a retransmission function, it can increase the arrival rate.

As an example, assuming one section between the assisted ball rollers is 35m, the cable extrusion time per tension application is 2 seconds, and the cable extension speed by ball is 35 m / min, 30 hello packets per section with extension ID will be sent out. In addition, the instruction packet to push the cable between the assisted ball rollers is provided with a delay of about 100msec, and after the cable is pushed out, the next assisted ball roller pushes the cable. If this delay time is too large, the cables may temporarily sag between the assisted ball rollers, and if the delay time is too small, the cables will be pulled between the assisted ball rollers and smooth cable installation operations cannot be performed.

C. Sequential Control of Multihop Transfer

In normal data communication, based on half duplex communication (transmission and reception switching), data is sequentially sent out in FIFO (First In First Out) while taking in data in the reception buffer according to the situation of carrier sense. Therefore, there is no guarantee that the previous data (n) is surely sent before receives the next data (n + 1). Figure 8 shows the data transfer mechanism with FIFO. Therefore, when the cable extension operation is performed using such a normal data communication method, when the operator applies tension to the cable head and the radio wave propagation condition is not good or traffic load is high. When instruction packets to push are stored in the memory of wireless device and cable extension does not immediately start. And when the operator applies tension to the cable head several times, the radio wave propagation situation is recovered and the traffic load is reduced. At this point, multiple push packets are output and the cable extension is performed many times.

At that time, depending on the section before and after the assisted ball roller, the slack of the cable temporarily and the slack cable are pulled at a stretch. Therefore, when performing the cable extension work using the normal data communication method, even if the push packet is received, there is a need that the extension is performed after confirming the state transition of the extension condition before and after.

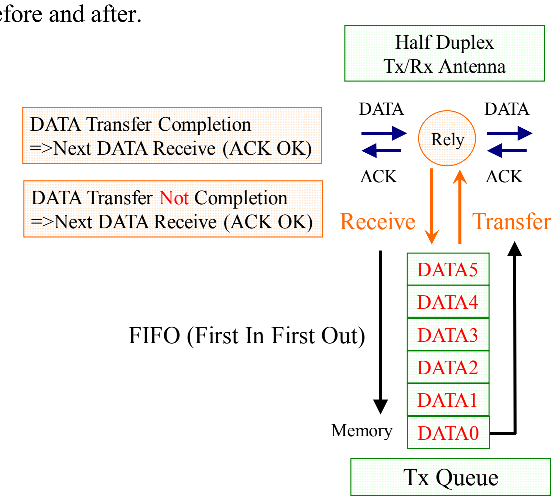


Figure 8. Data Transfer Mechanism with FIFO

However, it is difficult for the operator to match the memory of the number of times the cable is applied with tension and the number of times the cable is pushed to extension certainly. It is also necessary to consider the number of accumulated push packets with respect to the limit capacity of the reception buffer, and the number of lost push packets depending on the section of the assisted ball rollers. In order to make it easy for the operator to understand, if the cable is not extended within a fixed time after applying tension to the cable head once, multiple extension lines may be generated depending on conditions such as radio wave propagation and traffic. It retransmits over (including time out) in any section of the assisted ball rollers, determines that the push packet is lost, applies tension to the cable again, and waits for the cable to be extended. Therefore, for one push packet to extension, the next push packet is not received until the corresponding cable extension is completed. Figure 9 shows the data transfer mechanism without FIFO.

Specifically, within the time when the cable extension is not completed, the next push packet should be timed out without replying the response of ACK, with retransmission a certain number of times. Also, in the case of multi-hop transfer, wireless transmission of the extension assignment information may be established up to a certain section, so for push packets with the same sequence number in retransmission, the successful packet is a push packet even if the signal is received, the cable extension operation is not performed, and the cable extension operation is performed after the section where the wireless transmission is not established. Also in the case of this multi-hop transfer, a certain number of retransmissions are attempted. The setting of the number of retransmissions is also designed in consideration of QoE (Quality of Experience) as a balance between the delay time until the cable is extended and the waiting time etc. to be waited because the operator is in the process of retransmission.

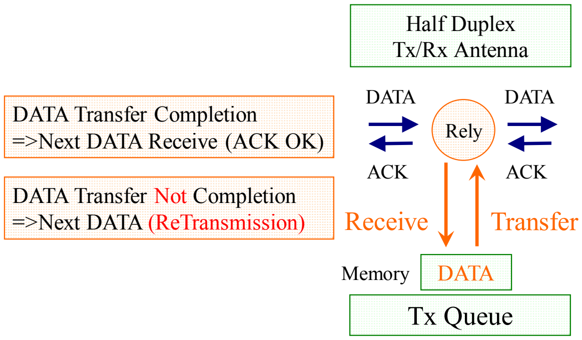


Figure 9. Data Transfer Mechanism without FIFO

D. Auto ACK Control

The multihop wireless device uses the DATA/ACK method, which enables transmission and reception handshake in a short time based on the physical layer without controlling the network layer up to down. Since ACK takes a relatively long response time due to carrier sense and back off procedures when it is generated from a DATA frame, auto ACK (BC: broadcast) with a quick response is used. However, if auto ACK is good in terms of radio wave propagation and FCS (Frame Check Sequence) is OK, it is automatically sent out even if the cable extension by the previous push packet is not completed. As described above, since there is no storage of DATA by FIFO, there would be a problem that although an auto ACK is issued, the corresponding push packet is discarded. Therefore, the auto ACK mode is stopped during the time when the previous push packet has not been transferred yet. When the auto ACK frame arrives from the transfer destination, the setting is made to switch to the auto ACK mode again [17].

IV. Experiment Result and Consideration

An experiment was conducted by placing five wireless devices using an IEEE 802.15.4 (/ ZigBee) [17] based CC 2520 (manufactured by TI) wireless chip [18] at the plant site. Figure 10 shows the layout in the plant.

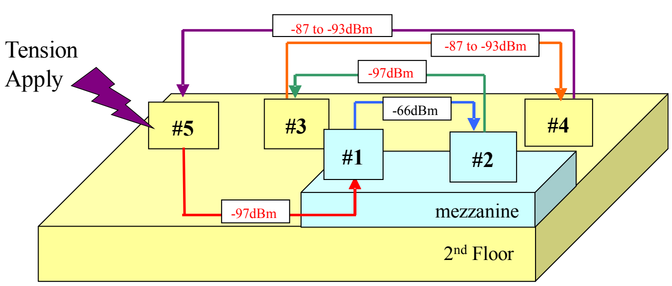


Figure 10. Layout of the Wireless Devices in the Plant

The wireless devices of which extension ID # 1 and # 2 were installed on the mezzanine cable shelf, and # 3, # 4 and # 5 were installed on the lower warehouse floor. This Figure 10 shows the received signal strength by hello packet in this arrangement situation, and there are the upper and lower sides of the building, the existence of walls and columns, a warehouse, the movement situation of workers and cranes, but # 1 to # 2 receive relatively strong which signal strength is obtained, Although the other sections fluctuate at around -90 dBm or less. Assuming that the threshold value for multi-hop communication or not is -90 dBm slightly higher than the minimum reception sensitivity (-95dBm) from DATA Sheet, multi-hop communication is estimated in the sections other than # 1 and # 2.

In the next hop selection of the relay terminal, the terminal with the highest received signal strength is selected with a small number of hops up to the target terminal. At that time, when there is no terminal having a value exceeding the threshold, it is designed to try direct communication (including retransmission). During the retransmission period, there is also a possibility that a multihop candidate relay terminal or a target terminal may be recognized. It is determined that the terminal has left without three consecutive hello packets, and in the opposite case, it has been determined that the terminal has entered three consecutive receptions. The route information is immediately updated due to the fluctuation of the received signal strength, and the RSSI value is averaged eight times of the symbol value at the time of carrier sense, and the averaging and the hysteresis setting are not performed again.

Figure 11 shows the experimental result. According to the experimental results when ten tensions were applied to extension ID # 5, the received signal strength of most relay terminals exceeds -90dBm in multi-hop communication. At the third time (# 3 to # 4 relays # 5 to # 4) and the fifth time (# 4 to # 5), the received signal strength of the relay terminal was -91 dBm. This seems to be because there is no relay terminal candidate higher than -91 dBm from the information of received signal strength from the Hello packet. It shows that the next hop selection of the relay terminal changes with the change of the received signal strength.

Cable extension order at multihop threshold level: -90dBm. Route information by tension applied to cable head #5 10times

			via.		via.		via.		via.	
1	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→	4	→ 3 →	5
	RSSI (dBm)		-80 -77		-69		-67 -79		-88		-88 -79	
2	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 5 →	4	→	5
	RSSI (dBm)		-75 -76		-69		-67 -80		-75 -90		-90	
3	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 5 →	4	→	5
	RSSI (dBm)		-76 -77		-69		-68 -79		-75 -91		-89	
4	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 1 →	4	→ 1 → 3 →	5
	RSSI (dBm)		-76 -79		-69		-67 -81		-78 -78		-77 -80 -75	
5	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 5 →	4	→	5
	RSSI (dBm)		-75 -79		-70		-68 -81		-75 -89		-91	
6	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 1 →	4	→	5
	RSSI (dBm)		-76 -78		-70		-69 -81		-79 -77		-89	
7	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 5 →	4	→	5
	RSSI (dBm)		-73 -78		-69		-66 -81		-73 -89		-88	
8	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 5 →	4	→	5
	RSSI (dBm)		-75 -78		-69		-67 -81		-73 -88		-90	
9	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 1 →	4	→	5
	RSSI (dBm)		-75 -79		-69		-66 -81		-78 -77		-87	
10	Roller	5	→ 3 →	1	→	2	→ 1 →	3	→ 5 →	4	→	5
	RSSI (dBm)		-75 -78		-69		-66 -81		-74 -87		-90	

Figure 11. Experimental Result.

Figure 12 shows the handshake time in transmission and reception using the IEEE 802.15.4 / ZigBee frame used in the experiment, and Figure 13 shows the throughput and handshake occurrence time according to the backoff time, respectively. For calculation, CW value in backoff is 31 to 1023 and slot time is 16 μsec / CW. The maximum length of the data frame is 133 bytes, the maximum length of the MAC frame is 127 bytes, and the payload part is 109 bytes. According to Figure 13, the difference of about 3 times in throughput according to the backoff time, and the backoff time during the handshake time occupies about 3/4 of the ratio, and the backoff time is greatly affected.

Figure 13 shows the DATA/ACK 2way handshake. The communication time by handshake of DATA / ACK is about 7 msec at CWmax = 100 slot, about 22 msec at CWmax = 1023 slot, and the center value (average value) is about half of the max value. In Figure 11, when the number of push packets (UC: unicast) by multi-hop communication per one try is eight hops, the total communication time is 8 x handshake time / min. In the experiment, the carrier sense of the push packet and the hello packet caused the contention for transmission, and the retransmission of the push packet due to the failure of the auto ACK packet was one out of ten (one place). The setting of the delay time until the cable is fed into the entire communication time is as long as 100 msec per one assisted ball roller, which is dominant in the entire cable extension time.

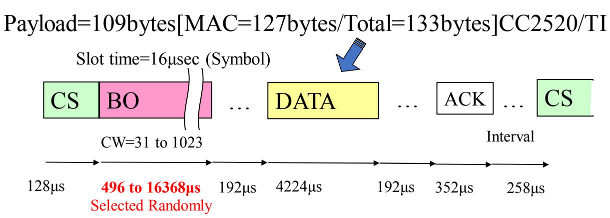


Figure 12. DATA/ACK 2way Handshake.

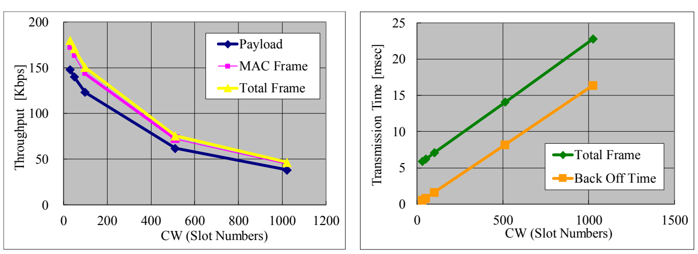


Figure 13. Throughput and Handshake Time

V. CONCLUSION

By applying wireless multi-hop communication to the control of the assist ball roller for cable installation, smooth cable extension work has become possible. Basically, it can be carried out by two people with a drum side and a cable front side, therefore a significant improvement in work efficiency has been realized.

As allocation from the real position where the wireless device arrangement is assigned to the wireless network, extension ID indicating the extension order in the hello packet and associating it with mac ID unique to the wireless device, sequential control without FIFO and auto ACK on/off switching control. We designed and manufactured a multihop wireless controlled cable installation system and realized the cable extension work in the experiment at the plant site.

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