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Cost-Efficient and Reliable Communication Scheme for Supporting a Mobile Device in WirelessHART of IIoT

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ABSTRACT In IIoT, WirelessHART is one of the reliable wireless network standards since it can improve the productivity and efficiency. Recently, in Industrial area, the enterprise and the researcher have been paid attention to a mobile device, which will become one of the key points in the industry due to its potential ability. However, since WirelessHART existing researches handle with a mobile device as a single point-to-point viewpoint, they will happen a disconnection and a wasteful communication resource problem when they use a mobile device. In order to solve this limitation, we propose a proactive and cost-effective scheme for the mobility by focusing on a mobility as a group viewpoint. By using onion-peeling method, the proposed scheme can select some fixed devices to communicate with a mobile device and prevent redundant communication provision for a mobile device. The simulation results show that the proposed scheme is more cost-efficient and reliable when it compares with the existing researches of WirelessHART.

INDEX TERMS Industrial Internet of Things, WirelessHART, cost-efficiency, reliability, mobility support.

I. INTRODUCTION

IoT (Internet of Things) is the concept that various objects and things with built-in sensors or communication modules communicate with the Internet and cooperate with neighboring devices in order to achieve a common goal [1]–[8]. In particular, the numerous global enterprises and researchers pay attentions to IIoT (Industrial IoT) because it affects the significant impact on global economy [9]–[15]. In IIoT, WirelessHART is one of the preferred wireless network standards in IIoT since it can improve the productivity and efficiency in IIoT [16]–[19]. Since WirelessHART is a standard that extends from the HART standard, known as the industrial wired communication standard, to the wireless communication in industrial environments, it is designed for industrial environments and attracted attention from industrial companies and researchers.

WirelessHART manages the paths and communication resources of the entire network in order to prevent the degradation of real-time and reliability due to the signal interference and collision that may occur in a wireless environment [20]–[27]. WirelessHART collects the data from each device and manages the paths and resources of the entire network in order to achieve the real-time and reliability requirements of industrial automation systems. WirelessHART utilizes a network manager, a centralized network management device, and all devices communicate on time based on TDMA. This allows the network manager to provide time for each device to communicate independently, thereby avoiding each device communication collision and reducing the power consumption of the devices. In addition, in order to provide a reliable network, the network manager establishes a primary path and a backup path for packet transmission from each device to the gateway. By establishing these paths, each device was able to lower the probability of communication failure.

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Recently, in Industrial area, the enterprise and the researcher have been paid attention to the mobile devices due to the emergence of the various intelligent devices [28]. According to the Factories of Futures report [28], [29], the support for mobile devices in the industrial area is considered one of the key point of the wireless requirements. The mobile device can simply define the device with the wheels [30]. Unlike the fixed devices, the mobile devices can move from current place to other positions and it can communicate with other devices [31]. For example, the automatic guided vehicles (AGV) [32], [33], one of the mobile devices, can perform the various tasks such as moving materials and finished goods or loading trailers, etc. Moreover, the mobile device uses the wireless medium so that it can communicates other devices.

However, in viewpoint, since the existing WirelessHART researches look at a mobile device as a single point-to-point viewpoint, there is a disconnection problem and a wasteful communication resource problem when they use a mobile device. In WirelessHART, Song's research [34], one of the representative researches, introduces the graph generation methods that are not described in this standard. In this research, there are three type of the reliable graphs for the reliable communication of the devices. Another research [35] focuses on the recovery about the connection failure between fixed devices by distributing graph generation. However, when these researches use a mobile device, there is a problem of continuous disconnection of path between a mobile device and a fixed device since these researches handle the mobile device as a single point-to-point viewpoint. The existing research [36], [37] proposes a new scheme by preparing the the paths for a mobile device based on all fixed devices in order to cope with the continuously movement of mobile device. However, this scheme wastes the unnecessary WirelessHART's communication resource by using all fixed devices for a mobile device. Therefore, since those existing researches focus on the viewpoint that looks at a mobile device as a single point-to-point viewpoint, it leads the continuous disconnection or the wasteful communication resource in WirelessHART network.

In order to solve this limitation, we propose a proactive and cost-effective scheme for the mobility. Unlike the existing WirelessHART researches by focusing on a mobile device as a single point-to-point viewpoint, the proposed scheme focuses on supporting mobility as a group viewpoint. For supporting mobility as a group, the proposed scheme selects some fixed devices to communicate with a mobile device by using the onion-peeling method that excludes their neighbors to reduce the unnecessary communication with the mobile device. By using this method, the proposed scheme can avoid to select the unnecessary communication resources about the region that overlaps fixed devices between their communication area and the mobile device. When the proposed scheme finishes to find the fixed devices to communicate the mobile device, it generates the reliable graphs between the mobile device and their selected fixed devices in order to provide the continuous communication for the mobile device. Through the proposed scheme, it can reduce unnecessary communication resource of WirelessHART and reduce unnecessary energy consumption of the devices by using some fixed nodes when communicating with mobile devices.

The organization is as follows; we describe the existing researches of WirelessHART and their limitation in chapter II. In chapter III, we introduce how to select some fixed devices that communicate with the mobile device and make the reliable grapsh for mobility support. The chapter IV shows the performance evaluation between the existing researches of the WirelessHART and the proposed scheme. Last chapter V describes the conclusion.

II. RELATED WORK

The existing WirelessHART standard shows only the description of the graph required for routing and of resource allocation, and there is no explanation about how to generate the graph and how to allocate resource. In order to provide the reliable communication between devices in WirelessHART, this research [34] introduces how to generate the reliable graphs required for routing in WirelessHART standard in details. This research introduces three type of reliable graphs for data transmission; one is a broadcast graph, another is an uplink graph, the other is a downlink graph. The network manager collects the information from the devices connected in the network in order to generate three types of the reliable graphs. Each graph has more than at least two paths and therefore, it can improve the reliability of the paths in the graphs. When a network manager wants to announce the information of node deployment and the control message to the nodes, it uses the broadcast graph. When each node wants to transmit the process data to a network manager, it regularly uses the uplink graph. When a network manager wants to transmit the data message to a device, it uses the downlink graph. This scheme shows how to make each reliable graph by using the located devices with the rule of WirelessHART standard. Another existing research [35] focuses on the recovery about the connection failure between fixed devices. This research describes that the centralized management causes the delay during the communication recovery step and the overhead to all fixed devices. This research introduces how to generate distributed graph routing on the device itself and tries to reduce the overhead between the fixed devices during the communication recovery step. Another research [38] proposes a efficient scheme to utilize the communication resources in order to save the limited resource of WirelessHART. In traditional WirelessHART researches, since a network manager initially generates a path from a node close to the network manager, this scheme proposes a resource efficient scheme by reducing duplicated paths from each node to the network manager.

However, like a traditional WirelessHART standard, since these researches only handle with the fixed devices, it is hard to provide the mobility for the mobile devices. When these researches exploit the mobile device in the network, they frequently disconnect with the fixed devices connected to the

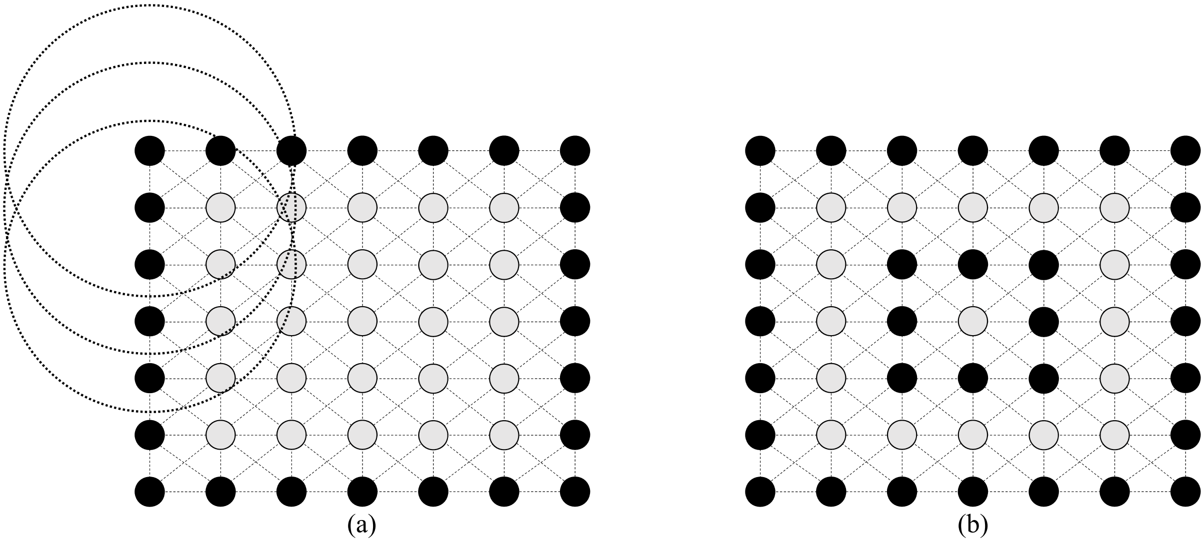


FIGURE 1. **Example of the global node selection.**

mobile devices because the mobile device moves other places continuously. Although a network manager tries to recover the connection failure, a mobile device still moves other place from current position. Since those researches focus on the viewpoint that looks at a mobile device as a single point-to-point viewpoint, it leads the continuous disconnection for a mobile device.

In order to communicate with a mobile device continuously, this research [36], [37] pre-generates the graphs for the mobile device in the initial setting of network. This research prepares three graphs based on all fixed devices at first. By using this step, this research can reduce the overhead of a connection because it just recovers the connection about a mobile device. For example, if a mobile device is set as the intermediate nodes, since a mobile device moves to another location, the graphs with a mobile device will disconnect a mobile device and connected fixed devices with a mobile device. After a mobile device disconnects with consisted graphs, it requests the path regeneration to a network manager and it leads the heavy delay and cost of the graph reconstruction. In order to avoid this situation, this research pre-generates three graphs together with all fixed devices and a mobile device after this step. Since a mobile device can move anywhere, this research pre-generates the graphs for a mobile device to guarantee the connection for a mobile device.

However, although this research provides the mobility and reduces the network changes for a mobile device, it leads the wasteful communication for a mobile device because it also handles with a mobile device as a single point-to-point viewpoint. Since this research prevents from the disconnection for a mobile device, all fixed devices prepare the connection for a mobile device even if it already supports the connection for a mobile device in same area. This result wastes the unnecessary communication resource because all fixed devices which locates in the same area pre-generate the paths for the mobile device.

In summary, sine the existing researches view a mobile device as a single point-to-point viewpoint, it leads the continuous disconnection or the wasteful communication resource in WirelessHART network. To solve limitation, we will approach a connection of a mobile device from a group viewpoint rather than a single point-to-point viewpoint in next chapter III.

III. PROPOSED SCHEME

In order to generate the reliable graphs of the WirelessHART, this paper utilizes the reliable graph generation method of the existing WirelessHART researches [34], [36], [37]. Although there are many research methods for the node selection to cover networks in the wireless field, it is difficult to find a node selection method suitable for the reliable graph generation method of the existing WirelessHART research that requires at least two paths when generating a node path. For this reason, this paper introduces a novel scheme for generating the reliable graphs by connecting at least two paths to the mobile device using existing WirelessHART research.

A. GLOBAL NODE SELECTION METHOD IN THE NETWORK

The first step of the node selection method, called the global node selection method in the network, finds the fixed devices to communicate with the mobile device based on the fixed devices in the boundary area. In the proposed scheme, the network manager identifies the boundary nodes that locates in the boundary area of the entire network at first. Since the mobile device can move to the boundary area of the network, the proposed scheme searches the fixed devices located in the boundary region of the network. In WirelessHART, since a network manager collects the information from all of devices, it can know where each device locates. Therefore, the network manager can find the fixed devices in the boundary area of the network and it can make the node group with those boundary nodes in the network.

As shown the figure 1(a), a network manager searches the farthest neighbor nodes based on each boundary node. Since each device can communicate with mobile devices as much as the radio range of its device, if it can provide the communication with its farthest neighbors, it will be able to communicate with mobile devices with the fixed devices anywhere in the network. When a network manager finds the farthest neighbor nodes based on each boundary node, the network manager is able to classify three type of the node groups. The first group consists of the boundary nodes of the entire network, the second group consists of the farthest neighbor nodes of the boundary nodes, and the third group consists of the neighbor nodes between the boundary nodes and their farthest neighbor nodes. After that, the network manager checks whether there are nodes included in the third group among the nodes included in the second group. This is because each boundary node has a different, farthest neighboring node, there may be nodes whose nodes contained in the second node group may be included in the third group. The network manager removes all nodes included in the third node group of the second node group, leaving only fixed nodes requiring to the communication of the mobile device. As a result, the first node group and the second node group forms into node groups to communicate with the mobile device, and the third node group divides into groups not to communicate with the mobile device. Therefore, like the figure 1(b), the network manager represented the first node group and the second node group to communicate with the mobile device as the black nodes and the third group not to communicate with the mobile device as the gray nodes. If the fixed node that does not contain among three groups still exists, the network manager repeats the node selecting process for the mobile node until all of the nodes contains among three groups. When a network manager finishes identifying the fixed nodes that communicate with the mobile device, it checks the boundary fixed nodes in first group and the farthest neighbor nodes in second group in order to allocate the communication resources for the mobile device. As shown the figure 1(b), the proposed scheme has the total adjacent 32 links connected between the boundary area nodes and it is able to reduce the unnecessary resource allocation for the communication of the mobile device than existing WirelessHART research.

1) ALGORITHM OF THE GLOBAL NODE SELECTION METHOD IN THE NETWORK

The notation of the algorithm 1 is as follows. In this notation, V denotes all nodes in the network and v presents a specific node selected. V_{B0} denotes a group that consists of the boundary nodes in network and V_{F0} presents a collection of the farthest neighbor nodes of V_{B0} and V_{F1}. V_{temp} is the temporary group in order to search the farthest neighbor nodes from V_{B0} and V_{F1}. V_{F1} is the group searching for the farthest neighbor nodes from the group of V_{temp}. V_{N0} denotes a node group to exclude the resource allocation from the network manager. This group consists of the neighbor nodes between V_{temp} and V_{F1}.

Algorithm 1 Algorithm of the Global Node Selection Method

```
$V_{B0} = \emptyset$, $V_{F0} = \emptyset$, $V_{F1} = \emptyset$
$V_{N0} = \emptyset$, $V_{temp} = \emptyset$
while one of $v$ is the node of the boundary area in $V$ do
    Find the node $v$ of the boundary area in $V$
    $v \subset V_{B0}$
end while
$V_{temp} = V_{B0}$
while $V$-$V_{B0}$-$V_{F0}$-$V_{N0}$ != $\emptyset$ do
    while $v$ is the farthest neighbor node in $V_{temp}$ do
        $v \subset V_{F1}$
    end while
    while $v$ is the neighbor node between $V_{temp}$ and $V_{F1}$ do
        $v \subset V_{N0}$
        if $v$ is the neighbor node in $V_{N0}$ then
            if $v$ is the farthest neighbor node in $V_{F1}$ then
                Remove $v$ in $V_{F1}$
                $v \subset V_{N0}$
            end if
        end if
    end while
    $V_{temp} = V_{F1}$
    $V_{F1} \subset V_{F0}$
    $V_{F0} = \emptyset$
end while
```

When the algorithm is executed, it initializes the values that represent the node group such as V_{B0}, V_{F0}, V_{F1}, V_{temp}, and V_{N0}. Then, this algorithm searches the nodes of the boundary area of the network among the entire nodes. In algorithm 1, when the network manager finds the boundary nodes in the network, it contains them to the group of V_{B0}, which is a set of boundary nodes, and this process is repeated until the boundary nodes for the network disappear. Therefore, after this repeat process finishes, the network manager can find the boundary nodes of the network. Then, this algorithm 1 puts the group of V_{B0} into the group of V_{temp}. After that, this algorithm starts to search the neighbor nodes of the nodes included in V_{temp}. As mentioned above, the reason that performs this process is to search for the unnecessary nodes to communicate with the mobile node and to prevent the unnecessary resource allocation to the WirelessHART. When the mobile node is connected with the unnecessary fixed nodes during the communication of the mobile node, the mobile node management area generated by the corresponding unnecessary nodes overlaps with the mobile node management area created by other fixed nodes. If resources are not allocated to nodes in the overlapped mobile node management area, this algorithm can save a considerable amount of resources than existing WirelessHART research [36], [37]. Therefore, the proposed scheme is able to identify the unnecessary fixed nodes when it communicates with the mobile node by performing the process that selects the neighbor nodes in V_{temp}. When the network manager finds the farthest neighbor node in V_{temp}, it contains to this node to the group of V_{F1}. After that, the network manager searches the neighbor nodes between V_{temp} and V_{F1}. Those neighbor nodes will exclude the resource allocation for the mobile device. The network manager contains those neighbor nodes to the group of V_{N0}. After that, the network manager finds the farthest neighbor nodes that is the group of the V_{N0} and V_{F1} because those farthest neighbor nodes are not the farthest neighbor nodes of the boundary nodes. When the network manager finds those farthest neighbor nodes, it removes those farthest neighbor nodes to the group of V_{F1} and contains them to the group of V_{N0}. Since the radio range of the node is limited in scope, the algorithm is difficult to find the all of the unnecessary fixed nodes in just one action. To solve this problem, this algorithm repeats until V-V_{B0}-V_{F0}-V_{N0} is empty. Before this algorithm repeats, V_{temp} sets V_{F1} and V_{F1} contains to V_{F0}. In addition, V_{F1} sets Ø.

B. INNER NODE SELECTION METHOD AMONG THE SELECTED NODES

In this section, the proposed scheme reduces the unnecessary communication for the mobile device by selecting some fixed devices in the network. In the global node selection, since the proposed scheme still includes unnecessary nodes among the selected boundary node area, it has the duplicated problem that overlaps the communication area of the mobile node between those boundary region nodes. In order to solve this problem, the proposed scheme uses a radio range of each device in order to reduce the overlapped communication region of the mobile device. The following section explains why the proposed scheme should use the radio range of the device.

Algorithm of the Inner Node Selection Method among the Selected Nodes: The proposed scheme proceeds with the node selection about the boundary nodes as shown in the figure 2. To describe the notation, V is the entire node and V_{B0} is the group that consists of the boundary nodes of V. This paper assumes that V_{B0} is a set of the boundary nodes and that it sets one by one into the array in one direction. Based on this assumption, when the network manager identifies the boundary area nodes, it registers in the array by circulating in either the right or left direction, so there is a first node and a last node in V_{B0}. Because of this, $v_{Initial}$ means the first array of V_{B0} and v_{Last} means the last array of V_{B0}. V_{C0} means the selected nodes by the corresponding algorithm in V_{B0}. That is, V_{C0} is a set of the fixed nodes to pre-allocate resources in order to communicate with the mobile node. In the notation, v_1 and v_2 are the selected nodes for use in this algorithm and r_v is the radius of the radio range of the node.

Algorithm 2 Algorithm of the Inner Node Selection Method Among the Selected Nodes

```
$V_{B0}$ is the group of the border nodes in $V$
$v_{Initial}$ is the starting point in $V_{B0}$
$v_{Last}$ is the last point in $V_{B0}$
$r_v$ is the radius of the radio range of the node
$D_{(v1,v2)}$ is the Distance between $v_1$ and $v_2$
$V_{C0} = Ø$,
$v_1 = v_{Initial}$, $v_2 = 0$, $D_{(v1,v2)} = 0$,
while $v_1$ != $v_{Last}$ do
    Find the farthest neighbor node $v_2$ of $v_1$ in $V_{B0}$
    if There is no neighbor node of $v_1$ in $V_{B0}$ then
        Unexpected Error
        Exit
    end if
    if $D_{(v1,v2)}$ is the smaller than $r_v$ then
        $v_2 \subset V_{C0}$
        else
        Find the neighbor node $v_2$ of $v_1$ in $V_{B0}$
        if $D_{(v1,v2)}$ is the smaller than $r_v$ then
            $v_2 \subset V_{C0}$
        end if
    end if
    $v_1 = v_2$
    $v_2 = 0$
end while
```

When the algorithm starts, v_1 sets to $v_{Initial}$ that is the starting point of the boundary area nodes. This algorithm repeats this search process until v_1 finds v_{Last} that is the last point of the boundary node. Thereafter, this algorithm searches for the farthest neighbor nodes of the selected node v_1 in V_{B0}. This process sequentially searches the neighbor nodes of v_1 with one searching direction in which the boundary nodes are searched in V_{B0}, not in both directions. After this algorithm 2 finishes to search the farthest neighbor nodes of the selected node v_1, it creates the link called $D_{(V1,V2)}$ from v_1 to the farthest neighbor node v_2. After that, when a link connected between each neighbor node and v_1 is created, this algorithm checks that the link is smaller to r_v, which is the radius. This process checks the lengths of the links between v_1 and the farthest neighbor node v_2 in order to check the appropriate link within a radius. When this link is smaller than r_v, then this algorithm puts v_2 in V_{C0} in order to select the boundary node for the communication of the mobile node. If the link length with the farthest neighbor node selected is longer than the radius of the radio range, only a rare case may exist because it is a case connected beyond the radio range of v_1. In this case, this algorithm finds and searches for v_2, one of a next farther neighbor nodes of v_1. Then connect v_1 and v_2 to generate a link and verify that the link length is less than the radius of the radio range. If the link is longer than the radius of the radio range, this is not possible and results in an error and exit the algorithm. The algorithm repeats until v_1 becomes v_{Last}. Through this process, it is possible to select the fixed nodes of V_{C0} to communicate with the mobile node and to provide the communication less the number of nodes than using all existing fixed nodes in the boundary area.

The following example is applied based on the algorithm of the boundary node selection. When the network manager selects the nodes to communicate with the mobile node, it identifies the boundary area nodes as shown in figure 2(a). As mentioned above, the proposed method searches the boundary area nodes in one direction by applying the searching assumption. Therefore, based on this assumption, the proposed scheme can show that the fixed nodes of the boundary area locate in one direction as shown in figure 2(b). In this figure, the light gray color node is the first node of V_{B0} and the dark gray color node is the last node of V_{B0}. The algorithm sets the light gray color node that is the first node to $v_{Initial}$ and the dark gray color node that is the last node to v_{Last}. When the algorithm reaches its last node, the dark gray color node, it is the last step in the search progress for the boundary area nodes, so it prepares to set the variable to stop the algorithm. As shown in the figure 2(a), this algorithm sets the first node, light gray color node, to v_1 and searches for the farthest neighbor based on its radio radius. Like figure 2(b), since this algorithm detects the neighbor nodes of v_1 in searched direction, it can search the farthest neighbor node v_2 that has the slash pattern as shown in figure 2(c). After that, the algorithm connects the link between v_1 with v_2 in order to check that this link is smaller than the r_v. The link between v_1 and v_2 is similar to r_v, the algorithm contains v_2 to the array of V_{B0}. After that, this algorithm sets v_2 to v_1 and it searches for the farthest neighbor node again around the v_1 that has the value of v_2 as shown the figure 2(d). The proposed scheme repeats this algorithm until v_1 arrives at the last node v_{Last} that is the dark gray color node. When this algorithm arrives at the dark gray color node that is the last point, it is able to provide the communication of the mobile node by connecting the first node $v_{Initial}$ in the V_{C0}.

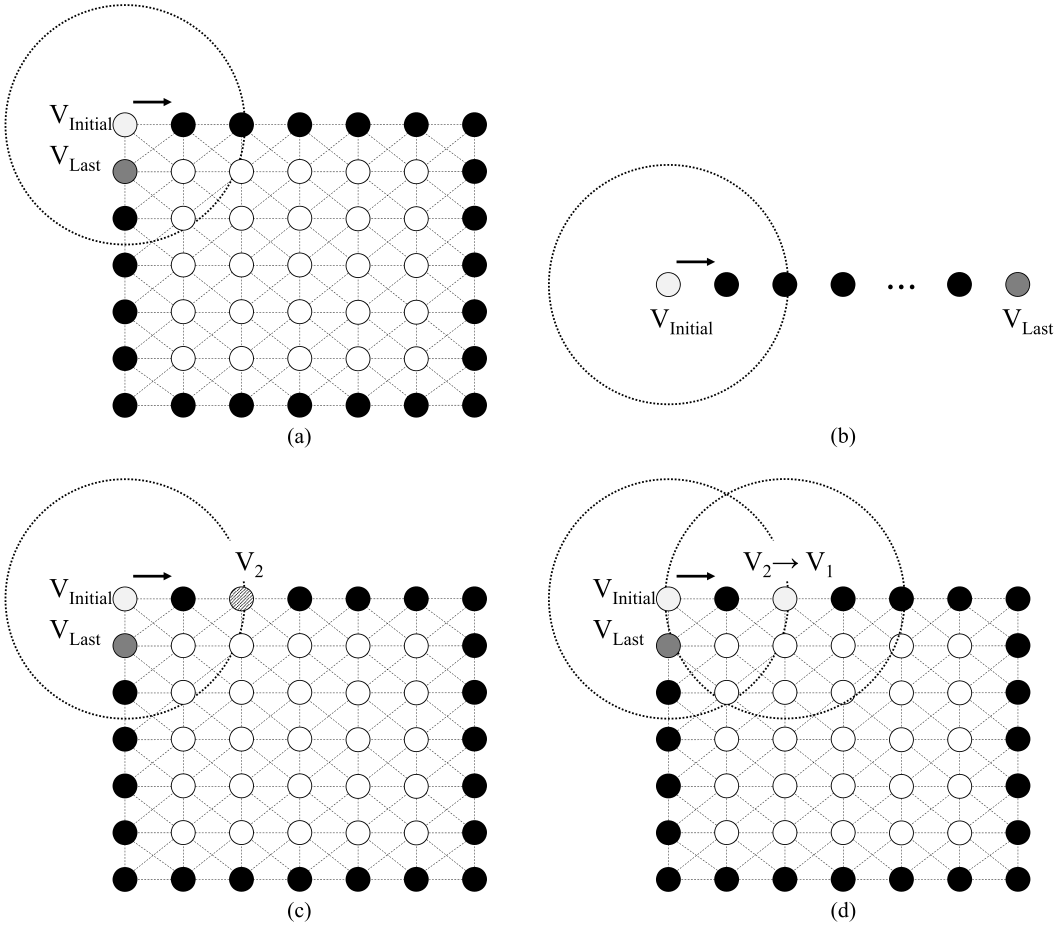
C. GRAPH GENERATION SCHEME FOR THE MOBILE DEVICE

The proposed scheme provides an efficient scheme to utilize the resource that requires to communicate with the mobile nodes by using onion-peeling method. The proposed scheme is generated in three steps: 1) creating the topology based on the fixed nodes, 2) selecting the fixed nodes to communicate with the mobile node, and 3) connecting the generated topology with mobile node. The first step, fixed node-based topology generation, distinguishes between the fixed nodes and the mobile node and then it creates a topology based on the fixed nodes. In order to provide the communication for mobile device by using the fixed nodes in the existing WirelessHART research, this step classifies the fixed node and the mobile node. Then, the proposed method exploits the second step in order to select some of fixed nodes to communicate with the mobile node. This second step does not utilize all of the fixed nodes but it selects some of them required for the mobile node to efficiently use the communication resources. This step identifies the fixed nodes in the boundary area of the network by using the onion-peeling method and then it selects the fixed nodes to communicate with the mobile nodes. After some of the fixed nodes to communicate with the mobile node are selected in the second step, the proposed scheme uses the third step that connects with the mobile node to the selected fixed nodes. The selected nodes in the second step and the mobile nodes pre-create the path between them so that the mobile node can always communicate regardless of the location. Like WirelessHART standard, the proposed scheme communicates through three graphs between the network manager and the nodes; one is the broadcast graph, another is the uplink graph, and the other is the downlink graph. This section describes how to generate three graphs.

1) GENERATION OF THE BROADCAST GRAPH

In WirelessHART, the broadcast graph is the graph that uses to forward the packets from the gateway to each node. The broadcast graph transmits to broadcast when the network manager transmits the control message about the entire network or when it notifies the node placement. The proposed scheme performs the first step that is the topology generation based on the fixed nodes when the network manager generates the broadcast graph. In order to minimize the network change for the mobile node, the proposed scheme classifies the fixed node and the mobile node by taking advantage of the existing WirelessHART research. After that, the network manager generates the broadcast graph based on the nodes that classifies to the fixed nodes. When the network manager generates the broadcast graph, this graph consists of the nodes that exist in at least two inner edges from outside, this is, the nodes that can receive the broadcast messages from two parent nodes. During the broadcast graph generation, the network manager can find the nodes that uses to generate the broadcast graph and it contain to the group of the broadcast graph. The network manager uses these nodes in the group of the broadcast graph to act as the parent nodes and they use later when the network manager is looking for the candidate nodes for the generation of the broadcast graph for mobile device.

After the network manager generates the broadcast graph based on the first step, it selects the fixed nodes to communicate with the mobile node by using the onion-peeling method of the second step of the proposed method. The proposed scheme searches the fixed nodes of the boundary area of the network in the generated broadcast graph and it selects the farthest node of the radius of the radio range in order to significantly reduce the number of fixed nodes to connect with the mobile node. By using this step, the proposed scheme can prevent the unnecessary resource allocation by not allocating the communication resource to the neighbor nodes of the boundary area nodes that are not the boundary area node. In this case, the network manager checks two groups; the group of the boundary area nodes and the group of the farthest neighbor nodes of the boundary area node. If there are the fixed nodes that not yet identified, it identifies the remaining fixed nodes to search based on the group of the farthest



(a) (b) (c) (d)

FIGURE 2. **Example of the inner node selection method among the selected nodes.**

neighbor nodes as if the onion skin is removed. The network manager repeats the searching process based on the group of the farthest neighbor nodes and then it can find the node to communicate with the mobile node. After that, a network manager generates the paths between the mobile node and the selected fixed nodes in a group of the farthest neighbor nodes. The process must also follow the same rules as in the first step, which causes the mobile node to connect from two parent nodes. Since the fixed nodes are already separated from each other at a certain distance in the second step, the mobile node can communicate with the network manager in the WirelessHART network by generating the paths in order with the fixed nodes selected in the second step.

Example of the Broadcast Graph Generation: Like the figure 3, this example assumes that there are one gateway, two access points, six fixed nodes, and one mobile node. The proposed scheme generates the broadcast graph based on the selected fixed nodes by performing the first step of the graph generation. When the network manager generates the broadcast graph, it creates the broadcast graph by selecting when a connection exists from two parent nodes in the figure 3(a). The network manager contains initially the A1, A2, and the gateway to the group of the broadcast graph. When the network manager searches the corresponding nodes according to the selection rules of two parent nodes, it can find the node 1 that is connected the parent node A1 and parent node A2. The network manager contains the discovered node 1 to the group of the broadcast graph, and thus, the nodes include in the group of the broadcast graph are the gateway, A1, A2, and node 1. Next, the network manager searches the node that has two parent nodes between the nodes that include the group of the broadcast graph, thereby it can find the node 2 that is connected the parent node 1 and the parent node A2. As in the previous procedure, the node 2 is included in the group of the broadcast graph. After the network manager contains the node 2 to the group of the broadcast graph, it can find the node 3 that is connected the parent node A2 and the parent node 2. The network manager contains the node 3 to the group of the broadcast graph and it can find the node 4 that is connected the parent node 2 and the parent node 3. After a network manager contains the node 4 in a group of a broadcast graph, it can find the node 6 that is connected the parent node 2 and the parent node 4. After a network manager contains the discovered node 6 to the broadcast graph group, it can find the node 5 that is connected the parent node 2 and the parent node 6. After a network

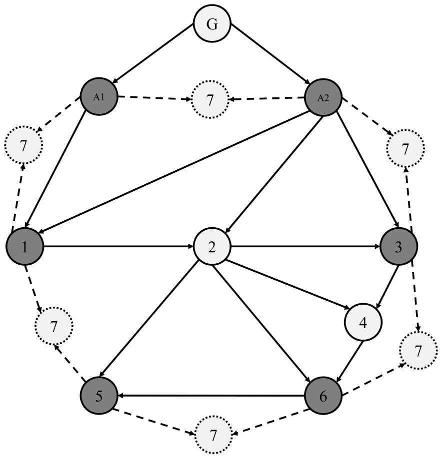


FIGURE 5. **Example of the connection with the mobile device in the broadcast graph.**

manager contains a node 6 to the broadcast graph group, it cannot find the candidate node. Therefore, the broadcast graph group is composed of A1, A2, node 1, node 2, and node 3, node 6, node 5 as shown the figure 3(b).

After the network manager finishes to generate the broadcast graph based on the fixed nodes, it selects the fixed nodes to communicate with the mobile node. As shown the figure 4, the broadcast graph searches the fixed nodes to communicate with the mobile node by using the proposed scheme called the onion-peeling method. The proposed scheme finds the nodes of the boundary area of the network in the broadcast graph composed of the fixed nodes through the network manager. When the network manager searches the nodes of the boundary area of the network close to the network manager, it can find the boundary area nodes, A1 and A2. When the network manager searches for the boundary nodes in one direction based on A1, it can find A2, node 3, node 4, node 6, node 5, node 1 in order. The network manager sets the starting node $v_{Initial}$ to A1 and sets the last node v_{Last} to the node 5. The search direction of the proposed scheme searches in the order from the starting node A1 to the last node 1 in the order of the searching the fixed nodes in the boundary region of the network. Then, the proposed scheme searches for the farthest neighbor nodes in broadcast group, and it can find the redundant node 2 and node 4. In this case, the proposed approach excludes the node 2 and node 4 because the other boundary nodes contain their regions and there are no other nodes except them. Thus, the fixed node of the group to communicate with the mobile node through the second step is composed of A1, A2, node 3, node 6, node 5, and node 1 as shown the figure 4. Based on this group, the third step is to establish a topology connection with the mobile node.

As shown the figure 5, the network manager generates the paths to be connected to the mobile node 7 in third step. The each fixed node of the group to communicate with the mobile node in the second step starts the connection with the mobile node 7. After the network manager generates the paths from A1 and A2 to the mobile node 7, it sequentially searches the next fixed nodes in the group to communicate with the mobile node in the second step. The selected fixed nodes to communicate with the mobile node 7 can maintain two paths within radio range by generating a path to the mobile node 7. For example, if the mobile node 7 exists between node A1 and node 1 in the figure 5, the mobile node 7 can maintain at least two paths, one is the path generated by the node A1 for the mobile node 7 and the other is the path generated by the node 1 for the mobile node 7. Consequently, the proposed scheme can maintain at least two paths wherever the mobile node moves, by generating the reliable paths from the selected fixed nodes to the mobile node.

2) GENERATION OF THE UPLINK GRAPH

In WirelessHART, the uplink graph is the graph that is connected from each node to the gateway and it periodically transmits the process data that generates from each node. When the proposed scheme generates the uplink graph, it is similar to generate the broadcast graph but it proceeds differently because some dissimilar parts exist. The first step for the generation of the uplink graph performs the step of the topology generation based on the fixed nodes in the similar way as the broadcast graph. Like the existing broadcast graph, the network manager generates the uplink graph based on the fixed nodes. When the network manager generates the uplink graph, it should be composed of the nodes that is connect from two children nodes by utilizing the existing method of generating the uplink graph of WirelessHART. The different point that compares with the broadcast graph is that the uplink graph should follow the rule that one node must have the outgoing connection with two nodes. This is, this means that there should be at least two edges exiting from one node, and in order to comply with this rule, the network manager does not utilize the original graph but it utilize the reversed original graph. The inverted original graph reverses the direction of all connected edges in the original graph and performs the work. Then, like the first step of the broadcast graph, when the network manager generates the uplink graph, it should select a fixed node with two or more incoming edges from other nodes. This is, when the network manager generates the graph according to the rule of the first step of the broadcast graph with the edge of the original graph in opposite direction and then when it changes to reverse the edge direction again, the network manager is able to keep the required rule of the uplink graph. For this reason, the network manager generates an uplink graph according to the first step rules of the broadcast graph in a situation where the edge direction is reversed. During this progress, the selected fixed nodes are included in the group of the uplink graph, and the nodes of this group can be used as the parent nodes when the network manager searches for new nodes to be included in the uplink graph. If the network manager generates the broadcast graph with the opposite edge direction through this progress, it completes to construct the uplink graph based on

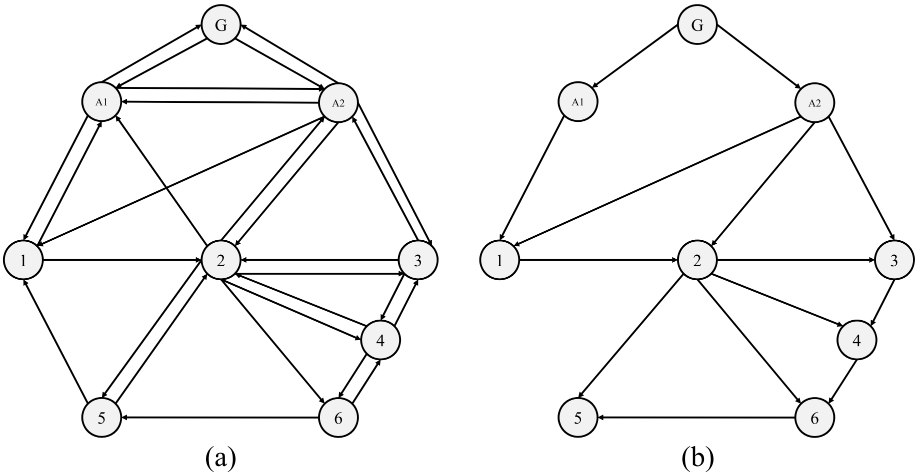


FIGURE 3. Example of the broadcast graph generation.

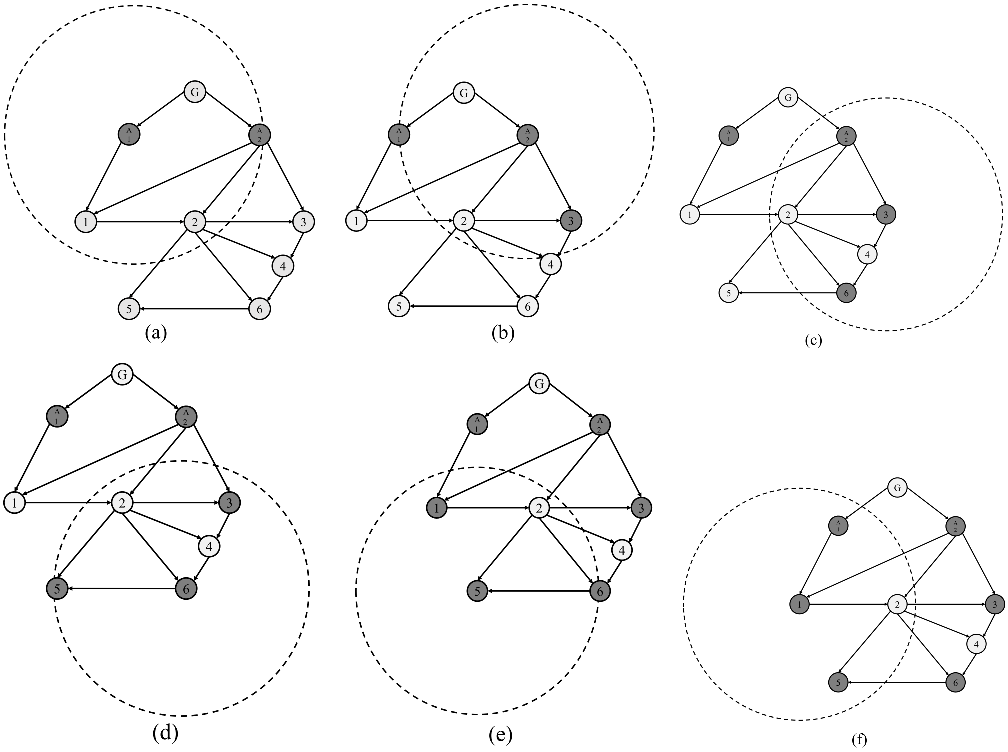


FIGURE 4. Example of the node selection in the broadcast graph.

the fixed nodes by changing the edge direction in opposite direction of the generated the broadcast graph again.

Then, the second step of the uplink graph is that reuses the broadcast group to communicate with the mobile node in order to prepare third step that generates the paths with these selected fixed nodes. The reason that the network manager does not perform the second step in the uplink graph is that the location of the fixed nodes of the uplink graph is the same as the location of the fixed nodes of the generated broadcast graph. If the network manager performs the second step of the uplink graph, it produces the same result as the second step in the broadcast graph because the location of the fixed node does not change. Because there is no need to repeat the second step of the uplink graph that produces the same result of the broadcast graph, the network manager does not execute the second step of the uplink graph but it reuses the group of the communication for the mobile node that is generated the broadcast graph in the second step.

After the network manager obtains the group to communicate with the mobile node from the broadcast graph in

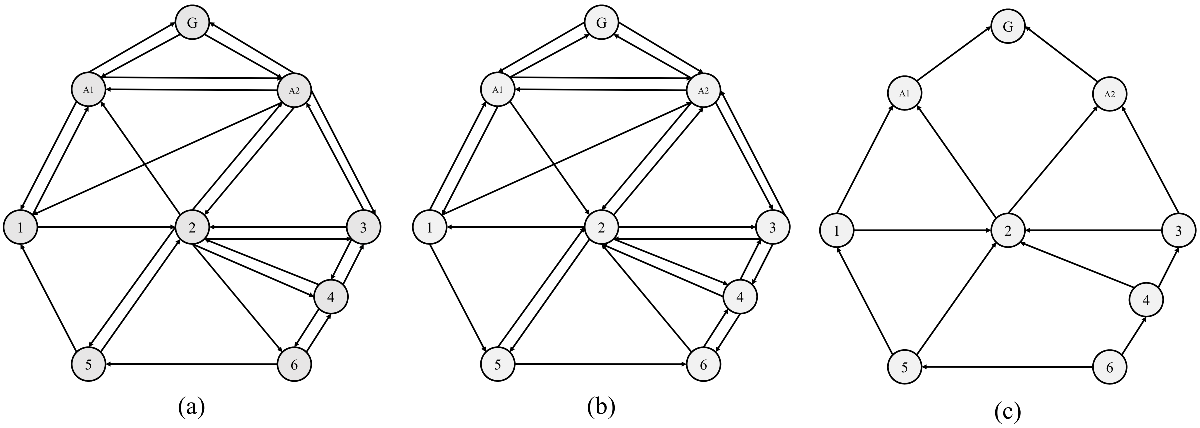


FIGURE 6. Example of the uplink graph generation.

the second step, it establishes the connection between the topology based on the fixed nodes and the mobile node. This process is similar to the third step of the generation of the broadcast graph, but it should be performed because the edge direction is different when the network compares with the generated broadcast graph. Like the third step of the generated the broadcast graph, the network manager generates the paths between the mobile node and the fixed nodes selected in the second step of the uplink graph in order to connect between the mobile node and these fixed nodes. In this process, the network manager follows the rule, that one node maintains two or more outgoing edges, performed in the first step of the uplink graph. Then, the network manager completes to generate the uplink graph by using third step of the uplink graph that connects to the mobile node.

Example of the Uplink Graph Generation: Like the generation of the broadcast graph, the figure 6(a) shows that there are one gateway, two access points, six fixed nodes, and the one mobile node. As mentioned above, the network manager generates the uplink graph based on the fixed nodes like first step of the generation of the broadcast graph. Before the network manager generates the uplink graph in this first step, it changes all of the existing edge directions to the opposite direction as shown in Figure 6(b). Then, like the first step of the generated broadcast graph, the network manager proceeds by selecting one fixed node that has two or more edges coming from other nodes. The initial group of the uplink graph is composed of the gateway G, A1, and A2 like figure 6(b). When the network manager searches one nodes in opposite direction of the original graph as the mentioned rule, the network manager is able to find the node 2 that connects to the parent node A1 and the parent node A2 among the fixed nodes in original graph. If the network manager searches the next candidate fixed node of the group of the uplink graph, it is able to find the fixed node 1 that connects to the parent node A1 and to the parent node A2. In addition, the network manager finds the next candidate fixed node 3 that connects to the parent node A2 and to the parent node 2. Through this search progress, the network manager is able to find the next candidate fixed node 5 that connects to the parent node 1 and to the parent node 2 among the members in the group of the uplink graph. Additionally, the network manager is able to find the next candidate fixed node 4 that connects to the parent node 2 and to the parent node 3 among the members in the uplink graph group. The network manager contains the discovered node 5 and node 4 to the group of the uplink graph. After that, a network manager can find the next candidate fixed node 6, that connects to the parent node 5 and to the parent node 4 of the group of the uplink graph. Therefore, the members of the uplink graph group are composed of the gateway G, A1, A2, node 2, node 3, node 1, node 5, node 4, and node 6. Since there is no node to contain to the group of the uplink graph anymore, it means that it is time to reverse the edge direction of the generated the uplink graph. After the network manager reverses the edge of all nodes of the generated uplink graph, it completes to generate the uplink graph based on the fixed nodes as shown figure 6(c).

Then, a network manager performs the second step that selects the fixed nodes to communicate with the mobile node. Unlike the broadcast graph, the second step of generating the uplink does not search the fixed nodes that communicate with the mobile node and it reuses the node group of the communication for the mobile node discovered in second step of the broadcast graph generation. As mentioned earlier, the uplink graph is similar to the broadcast graph, and the fixed nodes that use to generate the broadcast graph are the same location when the network manager generates the uplink graph because no fixed nodes have changed their positions. Therefore, the node group that communicates with the mobile node in the second step of the broadcast graph consists of A1, A2, node 3, node 6, node 5, and node 1.

As shown in the figure 7, the uplink graph generated based on the fixed node creates the paths with the mobile node 7 in order to connect to the WirelessHART network in the third step of the uplink graph. As mentioned above, the uplink graph uses the node group for the communication of the

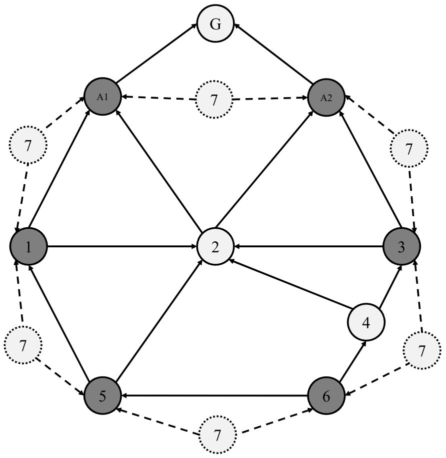


FIGURE 7. Example of the connection of mobile device in the uplink graph.

mobile node in second step of the broadcast graph generation. Like the third step of the broadcast graph generation, each node in this group can maintain two paths within radio range by generating a path to the mobile node 7. For example, if the mobile node 7 exists between node 1 and node 5 in the figure 7, the mobile node 7 can maintain at least two paths, one is the path generated by the node 1 for the mobile node 7 and the other is the path generated by the node 1 for the mobile node 5. Consequently, the proposed scheme can maintain at least two paths wherever the mobile node moves, by generating the reliable paths from the selected fixed nodes to the mobile node.

3) GENERATION OF THE DOWNLINK GRAPH

In WirelessHART, the downlink graph is the graph that is connected from the gateway to each device, and each device has each one graph. The downlink graph transmits the unicast message when the gateway or the network manager transmits the packets to each device.When the proposed scheme generates the downlink graph, it utilizes the information of the existing broadcast graph. The first step of the downlink graph performs the topology generation based on the fixed nodes in the same way as the first step of the broadcast graph generation. Unlike other graph generations, when the network manager generates the downlink graph, it does not exploit all of the fixed nodes. In other words, unlike the existing broadcast graph and uplink graph, the downlink graph generates a local graph per each device from the gateway to each node. When the network manager generates the downlink graph, there are three requirements as mentioned in the related work of the WirelessHART as follows.

1) The nodes should have at least two parent nodes and they are in cycles.
2) One of the two parent nodes, u_1, must be the parent node in the local downlink graph of the other parent node u_2.
3) u_1 or u_2 must have at least one parent node in the cycle of the local downlink graph.

Unlike the broadcast graph and the uplink graph, the downlink graph does not satisfy all of three conditions but it should meet the first and the second conditions, or the first and the third conditions. The nodes that generated the local downlink graph contains to the group of the downlink graph, and the network manager can use these nodes as the parent node later when it generates the downlink graph.The generation of the downlink graph repeats until all of the fixed nodes contains to the group of the downlink graph. After this iterative process is finished, the network manager completes the first step of the downlink graph generation.

The second step of the downlink graph generation is that the network manager selects the fixed nodes to communicate with the mobile node. In the second step of the downlink graph, like the second step of the uplink graph generation, the network manager reuses the group of the communication for the mobile node discovered in the second step of the generation of the broadcast graph. As mentioned above, unlike the broadcast graph and the uplink graph, the downlink graph does not use all of the fixed nodes but it utilizes some of the fixed nodes because it is the local graph. Since the downlink graph is the local graph, it should identify the location of all fixed nodes in the boundary region of the network in order to select the fixed nodes to generate the downlink graph. However, since this current progress is already searched for the fixed nodes to communicate with the mobile node during the second step of the broadcast graph generation, it is unnecessary to repeat the search process again when the network manager identifies the location of all fixed nodes of the boundary region of the network. Thus, by reusing the node group discovered in the broadcast graph generation, the network manager does not repeat to search again unnecessarily and it can perform rapidly the second step of the downlink graph generation.

The third step is to connect a mobile device with the topology consisted of the selected fixed nodes in second step. Like other third step of the broadcast graph and the uplink graph, a network manager identifies the selected fixed devices by checking the node group to communicate with a mobile node discovered in second step. Therefore, by using these fixed nodes, the network manager generates the paths for the mobile node in this step. Since all device should have at least two links according to WirelessHART standard, a mobile node should have at least two paths. When a mobile node has at least two paths, the mobile node can have the reliable downlink graph because one of the paths can use another path in case of damage. In this progress, the edge-direction for the generated path sets the inner edge-direction into the mobile nodes like the generation of the broadcast graph.

Example of the Downlink Graph Generation: As in the generation of the broadcast graph and the uplink graph, the figure 8 shows that there are a gateway, two access points, six fixed nodes, and a mobile node. As mentioned above, the network manager generates the local downlink graphs based on each fixed nodes at first as shown the figure 8. This process is generated by applying the downlink graph generation method

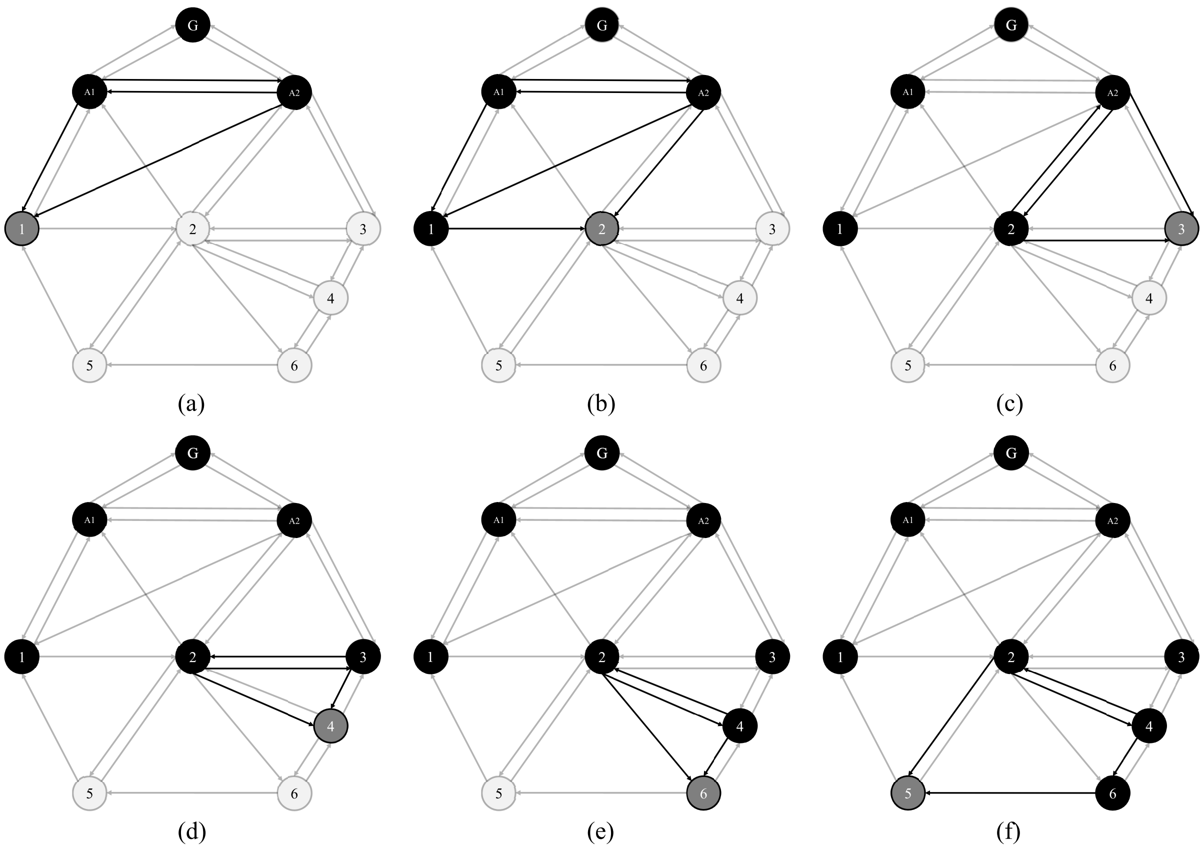
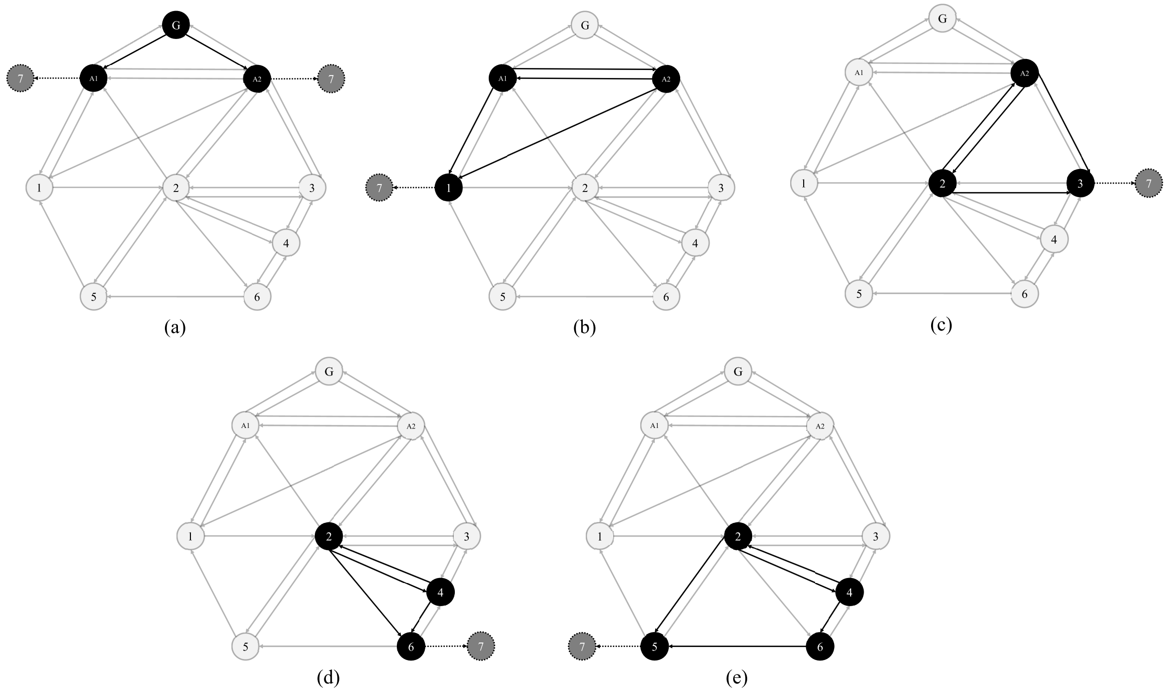


FIGURE 8. **Example of the downlink graph generation.**

of WirelessHART's existing research [34]. And then, it finds the selected fixed nodes that communicate with a mobile node in second step. The third step is that a network manager connects a mobile node with the selected fixed nodes. Each local graph for each node can include a number of nodes according to the graph of the parent node or it can consist of the downlink graph with a few nodes. In addition, when the network manager generates the local downlink graph for each node, it should follow the requirements as follows. The first condition for the generation of the local downlink graph is that the selected node should have at least two parent nodes and their parent nodes have to cycle. The second condition of the local downlink graph is that u_1, one of the two parent nodes, should be the parent node in the local downlink graph of the other parent node u_2. The third condition for the generation of the local downlink graph is that the parent node u_1 or other parent node u_2 should have at least one parent node in the cycle of the local downlink graph. Although the network manager can generate the local downlink graph to meet three requirements, the network manager generates the local downlink graph if it satisfies the first and second condition or the first and third condition. The nodes generated the local downlink graph include the node group of the downlink graph and they can use as the parent node later when the network manager generates the local downlink graph for the new node.

The initial group of the downlink graph is composed of total components; the gateway G, A1, and A2. When a network manager searches the node for generating the downlink graph to be a parent node among the nodes of the group of the downlink graph, it can find the node 1 as shown the figure 8(a). The node 1 can set the node A1 and the node A2 as the parent node in the downlink graph group, thus it can satisfy the first condition of the requirement that the node 1 should have at least two parent nodes. In addition, since there is a cycle between A1 and A2, the network manager can satisfy the first condition of the generation requirement of the local downlink graph. Moreover, since A1 can be the parent node in the local downlink graph of A2 or A2 can be the parent node in the local downlink graph of A1, the network manager is able to satisfy the second condition of the generation requirement of the local downlink graph of the node 1. As a result, since the node 1 satisfies the generation rule of the local downlink graph, it can generate the downlink graph as shown the figure 8(a). When node 1 generates the local downlink graph, the network manager contains the node 1 to the node group of the downlink graph, and this node group of the downlink graph is composed of the gateway G, A1, A2, and node 1. Likewise, a network manager generates other downlink graph according to the graph generation rule of the downlink graph generation [34]. As a result, as shown the



(a) (b) (c) (d) (e)

FIGURE 9. Example of the downlink graph generation.

figure 8, the fixed nodes that contains in the node group of the downlink graph are composed of the gateway G, A1, A2, node 1, node 2, node 3, node 4, node 6, and node 5.

The second step of generating the downlink graph performs the step of selecting fixed nodes to communicate with the mobile node. In this step, a network manager does not find the fixed nodes to communicate with a mobile node but it reuses the node group that found the second step in the broadcast graph generation. Since, the downlink graph does not configure all fixed nodes, it is difficult to find the fixed nodes to communicate with a mobile node in the network. This is, the node placement environment of the downlink graph is identical to the node placement environment of the broadcast graph based on the original graph utilizing all fixed nodes. The node group to communicate with the mobile node in the second step of the broadcast graph generation consists of A1, A2, node 3, node 6, node 5, and node 1.

The figure 9 shows the other nodes, in the group that communicates with the mobile nodes. The nodes have a common point that has each local downlink graph and a network manager utilizes the downlink graph of each node because it can reduce the overhead like the time of the local downlink graph generation. To eliminate this unnecessary process, the network manager utilizes the downlink graph of each node in order to generate the local downlink graph containing the path to the mobile node 7. Therefore, the figure 9 shows the downlink graph generation with the node group that communicates with the mobile node 7. If the nodes that will communicate with the mobile node generate the paths to the mobile node 7, the mobile node 7 can maintain at least two paths to any location. For example, if the mobile node 7 is located between the node A2 and the node 3, then the mobile node 7 can utilize the path of the downlink graph generated from the node A2 and the path of the downlink graph generated from the node 3. Therefore, the mobile node 7 can maintain at least two paths by using those paths. Therefore, the mobile node 7 can maintain at least two paths with those paths.

TABLE 1. The components of the simulation environment.

Simulation Component	Values
Network Simulator	MATLAB [39]
The Number of the Fixed Devices	8
Distance between the Fixed Devices	46 m
The Number of the Mobile Devices	1
Speed of the Mobile Device	1 m/s [40]–[43]
Mobility Model	Random Way Point Model [44]
MAC Protocol	802.15.4
Radio Range of the Device	46.42 m [45]–[47]
Simulation Repetition	40 times
Energy Consumption (TX)	57.42 mW
Energy Consumption (RX)	62.04 mW
Comparison Targets	WirelessHART (Re) [34] WirelessHART (Pro) [36], [37], Proposed Scheme

IV. PERFORMANCE EVALUATION

A. SIMULATION ENVIRONMENT

This section shows the simulation environment to explain the performance evaluation in details. This section exploits the Matlab simulator [39] to compare with the existing studies of WirelessHART and it describes the parameters in the table 1.

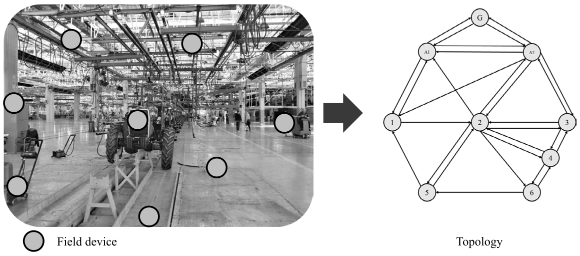


FIGURE 10. **Simulation topology.**

There are 9 static devices and there is one mobile device with 1m/s speed, similar to the products sold in the real environment [40]–[43]. This mobile device moves random position by using the Random Way Point model [44]. We assume that each device is MSP430 microcontroller with CC2420 chip in order to follow the real environment and the transmission range is 46.42m [45]–[47]. All devices use the 802.15.4 MAC protocol. The simulation repeats 40 times for each simulation graph and the simulation result sets the average value. The simulation results are consisted of two values; one is the average energy consumption of the device and the other is the average transmission success ratio. In addition, there are three variables used in the simulation compared to the existing studies; one is the speed of the mobile device, another is the distance between the devices, and the other is the number of mobile devices. There are two comparison targets in the simulation.

One is reactive WirelessHART research, which focuses on the fixed devices like the traditional WirelessHART researches. This session selects this research [34] as a representative among the reactive WirelessHART researches [34], [35], [38] because this scheme is a basic scheme in WirelessHART. This reactive research handles with the mobile device passively to provide mobility of mobile device. This chapter calls this research as WirelessHART (Reactive). The other is the research [36], [37], which actively provides the mobility by using all fixed devices for a mobile device. This chapter calls this research as WirelessHART (Proactive).

B. NETWORK TOPOLOGY

This section shows the network topology that uses the simulation. This chapter uses the network topology [34] used in the graph generation of WirelessHART in the Related Work. This network topology is similar to that of WirelessHART (Reactive) research [34] and WirelessHART (Proactive) research, and the simulation is conducted using this topology because the graph generation method for the data transmission can be applied in the same way. By comparing this topology with existing WirelessHART researches, this paper can show how improved when it is compared with the existing scheme.

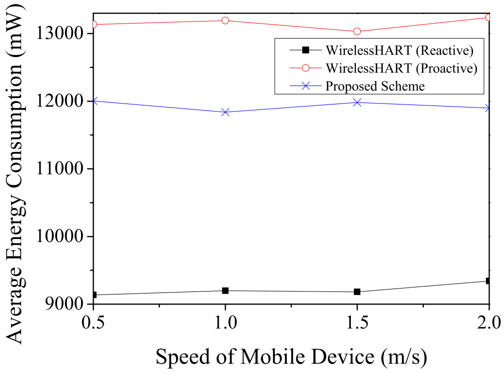


FIGURE 11. **Average energy consumption versus the speed of mobile devices.**

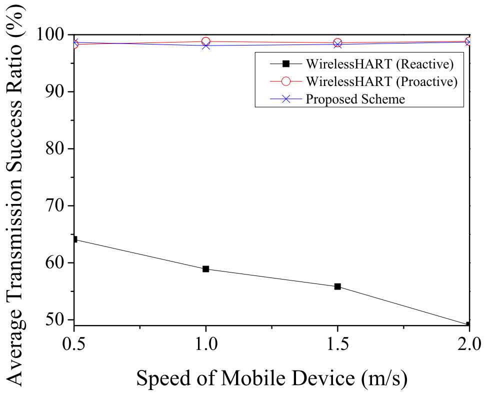


FIGURE 12. **Average transmission success ratio versus the speed of mobile devices.**

C. SIMULATION RESULT

The figure 11 shows the result graph of the average energy consumption versus the speed of the mobile device. In this simulation, the speed of the mobile device was increased from 0.5m/s to 2m/s in order to check the results according to the speed. In this figure 11, the WirelessHART (Reactive) among the three comparison targets has the lowest energy consumption compared with other two studies because it passively copes without pre-generating the paths for the mobile device. WirelessHART (Reactive) is partially changed depending on the fixed nodes that is connected to the mobile device, and it has similar average energy consumption depending on the increased moving speed as shown in figure 11. On the other hand, WirelessHART (Proactive) has the most average energy consumption of devices among the three comparison targets because it pre-generates all the paths a mobile device can take, even if the mobile device is located elsewhere. When the proposed scheme compares with WirelessHART (Reactive) and WirelessHART (Proactive), its average energy consumption locates in the middle position between them.

The figure 12 shows the result graph of the average transmission success ratio versus the speed of the mobile device. In this simulation, the speed of the mobile device was increased from 0.5m/s to 2m/s. In this figure 12, the WirelessHART (Reactive) has the lowest transmission success ratio that continues to decrease compared with the speed because it passively generates the paths for the mobile device.

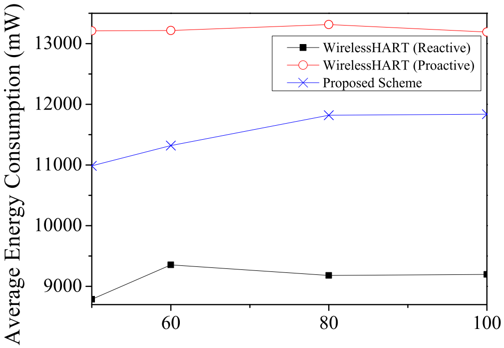


FIGURE 13. **Average transmission success ratio versus the distance between the devices.**

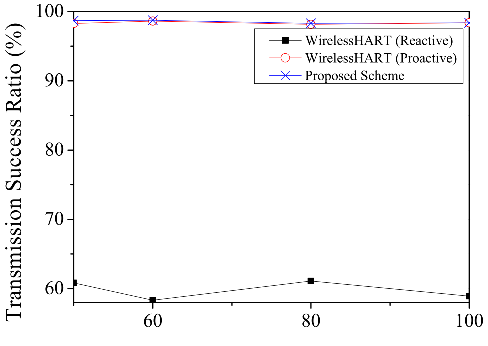


FIGURE 14. **Average transmission success ratio versus the distance between the devices.**

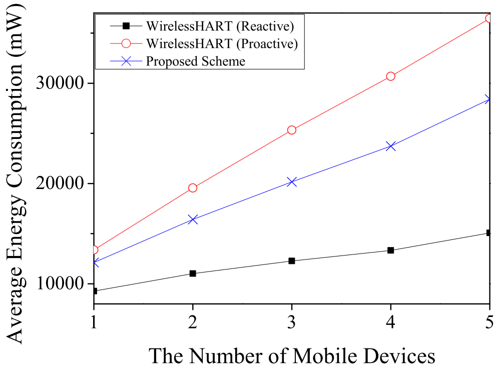


FIGURE 15. **Average energy consumption versus the number of the mobile devices.**

Since the mobile device moves continuously, as the speed of the mobile device increases, WirelessHART (Reactive) has the chances to fail to connect with the paths from near neighbors. On the other hand, WirelessHART (Proactive) and the proposed scheme almost have an average transmission success ratio of 100% because two researches pre-generate the paths for a mobile device, they can maintain the higher average transmission success ratio wherever the mobile device arrives. In the case of WirelessHART (Proactive), all fixed devices have already created paths for the mobile device, so they can always connect even if the mobile device location changes. The proposed scheme does not utilize all the fixed devices but it selects some fixed devices to communicate with a mobile device, it can provide the connection with a mobile device even if the mobile device location changes.

The figure 13 shows the resulting graph of the average energy consumption versus the distance between the devices. In order to check the results according to the density of the devices, this simulation decreases its distance from 100% to 50%. The WirelessHART (Reactive) has the lowest energy consumption compared with other two researches since it passively copes with the paths for the mobile device. WirelessHART (Reactive) also changes its results like the figure 13 because the connected fixed nodes are changed according to the distance between the devices. The WirelessHART (Proactive) has the highest average energy consumption of devices because it uses all fixed devices for the connection with the mobile device in advances. This research does not affected by the distance between devices due to the all pre-generated paths for a mobile device even if the distance between devices is reduced. As shown the figure 13, the proposed scheme has the middle position between two comparison researches because it does not utilize all fixed devices like WirelessHART (Proactive) but it pre-generates the paths for mobile devices based on selected fixed devices. When it selects the fixed devices to communicate with the mobile device, it selects the farthest neighbor nodes from the radio radius. As the distance between devices decreases, the unnecessary fixed devices to connect with the mobile device in the radio radius of one fixed device increase. The proposed method can reduce the number of unnecessary fixed devices by utilizing the farthest neighbor device, thereby gradually reducing the number of fixed devices to communicate with the mobile device like the figure 13.

The figure 14 shows the resulting graph of the average transmission success ratio versus the distance between the devices. This simulation decreases the distance between the devices from 100% to 50% to check the density of the devices. WirelessHART (Reactive) has the lowest average transmission success ratio among the three comparisons because it does not prepare the paths for the mobile device. Since it does not prepare the paths for a mobile device, it frequently disconnects and reconnects with the mobile device and it results in reducing the average transmission success ratio. On the other hand, WirelessHART (Proactive) almost have an average transmission success ratio of 100% by using all fixed devices for the path pre-generation to the mobile device. It means that even if the location of the mobile device changes, the mobile device can connect the paths prepared by the fixed devices. The proposed scheme also higher average transmission success ratio since it is possible to provide communication with a mobile device by selecting the some fixed devices that can cover the network. Therefore, since the WirelessHART (Proactive) and the proposed scheme pre-generate the paths for a mobile device, they can maintain the higher average transmission ratio than the WirelessHART (Reactive).

The figure 15 shows the resulting graph of the average energy consumption versus the number of the mobile devices.

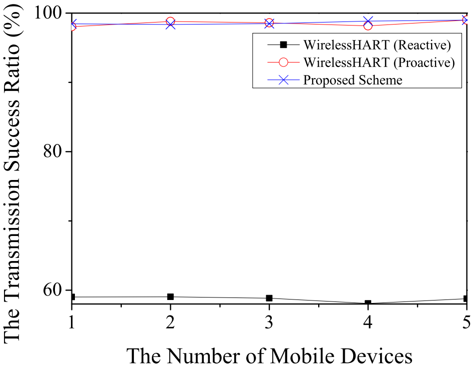


FIGURE 16. Average transmission success ratio versus the number of the mobile devices.

In the simulation, the number of the mobile devices sets from 1 to 5 in order to check the results as the number of mobile devices increases. Compared with three comparison targets, the WirelessHART (Reactive) has the lowest energy consumption because it handles with the mobile devices as a passive way of generating paths to mobile devices whenever they are found. As the number of mobile devices increases, only the paths required for each mobile device are generated, and then it results in the increased average energy consumption. On the other hands, the WirelessHART (Proactive) has the highest average energy consumption of devices because it generates the paths of all fixed devices for the mobile devices in advances. When the mobile device adds in the network, the WirelessHART (Proactive) prepares to the additional paths for the mobile device from the all fixed devices. Since this research pre-generates the additional paths for the mobile device from the entire fixed devices, it has the highest average energy consumption of the devices compared with other two studies. The proposed scheme consumes more energy than WirelessHART (Reactive) because it prepares fixed devices to communicate with mobile devices in advance, similar to WirelessHART (Proactive). Compared with the WirelessHART (Proactive), the proposed scheme generates the additional paths for the mobile devices by selecting some fixed devices to communicate with the mobile device, so the average energy consumption is lower than that of WirelessHART (Proactive).

The figure 16 shows the resulting graph of the average transmission success ratio versus the number of the mobile devices. In the simulation, the number of the mobile devices sets from 1 to 5 in order to check the results as the number of mobile devices increases. The WirelessHART (Reactive) has the lowest average transmission success ratio when it compares with two simulation target because it does not pre-generate the paths for the mobile device. As above mentioned, the WirelessHART (Reactive) initially generates the paths for the mobile device but those paths do not maintain because the mobile devices move other location by using the Random Way Point model. WirelessHART (Proactive) has the higher average transmission success ratio when it compares with WirelessHART (Reactive) because all fixed devices pre-generate the path to each mobile device. Since all fixed devices pre-generate the additional paths for each mobile device, this scheme has the high transmission success ratio when the number of the mobile devices increases because each mobile device uses the pre-generated paths where each mobile device located. Similarly, the proposed scheme has the higher average transmission success ratio because it selects fixed devices to communicate with the mobile nodes and pre-generates the necessary paths for each mobile device. Therefore, since WirelessHART (Proactive) and the proposed scheme generate the additional paths for each mobile device in advance, the higher average transmission success ratio can be maintained than the WirelessHART (Reactive) by using the generated paths even when the number of the mobile devices is increased.

V. CONCLUSION

IIoT, industrial area among the several IoTs, improves productivity and efficiency through industrial automation systems that satisfy the industrial requirements that are the real-time and reliability. In IIoT, WirelessHART is one of the prefered wireless network standards since it can guarantee the industrial requirements that are the real-time and reliability. Recently, most enterprises and researchers pay attention to the mobile device because it can use the various tasks in IIoT. However, since the existing WirelessHART studies treat the mobile device as a single point-to-point viewpoint, they the disconnection problem with the mobile device or wasteful resource problem in WirelessHART. To solve those limitation, the proposed scheme focuses on the mobility support as a group viewpoint, not a single point-to-point viewpoint. In order to support the proactive and the cost-efficient mobility, the proposed scheme selects some fixed devices and pre-generates the paths to communicate with a mobile device. Through node selection scheme, the proposed scheme can support the reliable mobility support and reduce the wasteful communication resource in WirelessHART. The simulation results show that the proposed scheme higher reliable average transmission success ratio with lower energy consumption compared with the existing WirelessHART researches.

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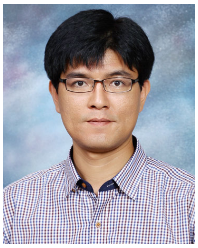

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