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MULTI-CONTROLLER SDN FOR WIRELESS HETEROGENEOUS NETOWORKS

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ABSTRACT

The state-of-art network has become very complex and heterogeneous to accommodate explosively increasing traffic. In a wireless heterogeneous network, users experience handover between heterogeneous radio access technologies. By separating the control plane from the data forwarding plane, software-defined networking (SDN) enables the flexible management of heterogeneous wireless network resources. However, the performance of a single-controller SDN is limited and difficult to manage with flexibility and agility. The deployment of multi-controllers is more desirable in this kind of networks to improve the scalability and reliability of the control plane. This paper proposes a novel network architecture with loosely-coupled multi-controllers. The loosely-coupled method applied with a multi-controller architecture brings two benefits: one to reduce overburdened control messages to the controller and the other to assure fast response time. Through numerical analysis, we demonstrate that our proposed multi-controller architecture reduces handover cost by 28% and handover delay by 23% compared to the traditional structure. Our architecture also exhibits superior performance compared to other prior architectures in terms of both handover cost and delay, and thereby the proposed multi-controller architecture being an efficient solution for managing the ever-increasing network traffic.

Keywords: *Software-Defined Networking, Multi-Controller, Heterogeneous Network, Loosely-Coupled Network, Handover*

1. INTRODUCTION

Software-defined networking (SDN) [1][2] is representing a technical concept that a network can be defined through software. SDN is a novel network architecture which separates control plane from data forwarding plane. The SDN controller allows central management with a global network topology. It can control the network traffic by OpenFlow protocol [3].

Interworking between heterogeneous networks is an important issue to redistribute data traffic and increase network stability. There has already been a lot of research on how to integrate Long-Term Evolution (LTE) [4] and Wireless LAN (WLAN) in traditional network environments. It is described in detail in [5], a standard document that represents the 3rd Generation Partnership Project (3GPP) based network integration architecture. At present, some scholars have studied efficient integration. Andreev et al. [6] focus on interworking within a wireless access network and detail explain feasible options for intelligent access network selection. In the heterogeneous network, intelligent network selection will be an essential feature for the efficient use of multiple RATs. Alsohaily and Sousa [7] proposed using multi-RAT carrier aggregation to improve the performance and spectrum utilization of multi-RAT systems. Research is also underway on interworking between the 5g network and other networks. Tayyab et al. [8] present the general concepts of wireless access mobility in cellular networks. However, these studies have architecture limitations. The architecture required by special gateways increases costs and requires additional security. This paper improves the scalability and efficiency of the network with a loose-coupled architecture based on SDN.

The traditional SDN implementation relying on a controller has limitations related to scalability and performance [9]. A single-controller does not have enough performance to handle the explosive increase in control messages. The current network environment requires an excessive amount of

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information and wants to handle it frequently. And it is required to deliver and receive more quickly. However, it is difficult to resolve the problem with a single-controller with insufficient message processing capacity and speed [10]. SDN controllers have different performances (number of flows per second) and do not have sufficient performance. Another problem with a single-controller is that if a controller encounters a problem, it affects the entire network. Various solutions have been proposed to address these issues. Heller et al. [11] proposed a load balancing algorithm for controllers. To show that the answer to where and how many controllers to deploy. One controller location is often sufficient to meet existing reaction-time requirements. It is important to know where is a controller and how many controllers are needed. Sallahi and St-Hilaire [12] proposed a complete model to solve using deployment cost for the multi-controller deployment problem.

In this paper, to solve the problem of single-controller through a multi-controller with a loosely-coupled method. However, it is essentially difficult to reduce control messages effectively in traditional ways. It is necessary to consider how to handover between heterogeneous networks. 99.70% of control messages were generated to change the flow table [13]. These messages are intended to change the path of the packet. It is possible to reduce a lot of load on the controller by reducing the handover message generated when the terminal moves. As other studies have shown, the deployment of multi-controllers is the key issue. Various methods exist, but broadly, they are divided into a flat method [14-17] and a hierarchical method [18-22]. Structurally, interpreting two methods is as follows: The flat architecture, the controllers are widely distributed. Each controller manages its own area and shares information through east-west bound interfaces. Compared to the single-controller architecture, the controller is less burdened, and it is possible to expand the function of the control plane. However, it is difficult to manage controllers in an integrated manner, requiring additional control overhead. In flat architecture, it is necessary to communicate and share information between controllers at short intervals. Local controllers are difficult to have overall topology information, so it takes time to get the information to solve the problem. Problems between local controllers nearby can be solved quickly, but local controllers far away require a lot of time. To solve these problems, a method with hierarchical architecture is proposed. A hierarchical architecture is a controller that uses multiple layers. Each SDN area is managed through a Local controller, and the information sharing between controllers enables global controller to be integrated through north-southbound interfaces. However, this hierarchical approach causes a lot of propagation latency as the number of layers increases. It is easy to see that the decision location affects the decision latency. The closer a task's decision location is to the data plane, the lower the controller's processing latency. We can use this to our advantage by controlling through the closest controller possible, which will result in faster response times. To accomplish this, a hierarchical architecture allows the global controller to have global topology information and local controllers to have local topology information. This has the advantage of being able to respond faster.

The proposed architecture to solve these problems uses the loosely-coupled architecture. The loosely-coupled architecture was difficult to apply because it was difficult to solve problems such as IP continuity, although it was possible to solve the problems of the traditional architecture. Using a loosely-coupled architecture in a network environment with SDN is possible to increase the flexibility or scalability of the entire network. The paper [23], explained in detail the handover method between LTE and WiFi in the loosely-coupled method with multi-controllers. In addition, describes the handover procedure from traditional to the proposed architecture. To explain in detail what message the handover process is through. Our research proposes a novel handover procedure which enables efficient message compression and stage reduction. By integrating a loosely-coupled structure with SDN in a multi-controller network architecture, we have managed to significantly reduce both the handover cost and delay. This is achieved due to the capability of the proposed structure to streamline the procedure, thereby decreasing the number of necessary messages and steps involved in the process. This unique approach positions our method as a highly advantageous alternative over traditional methods in terms of both handover cost and latency.

The rest of the paper is organized as follows. Section II summarizes previous related works. Section III briefly describes the proposed architecture and handover procedure. Section IV and V discusses numerical analysis and results. Section VI provides our concluding.

2. RELATED WORK

Multi-controller architecture is a concept that divides the network into multiple SDN domains and controls them separately through multiple

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controllers. These multiple controllers typically include a local controller that controls each zone and a separate global controller that oversees the entire network. The global controller's primary function is managing all controller loads, with the flow counts for each domain being regularly collected from the local controllers. The local controllers periodically manage their respective domains and provide pertinent information from the switches, forming a cross-controller interaction system. Utilizing this system, the global controller monitors the traffic load based on the information relayed from the local controllers. Consequently, it executes a load balancing algorithm and redistributes the switches to mitigate the load problem of control messages that can occur in each local controller. This system's effectiveness in managing controller loads is a crucial aspect that we have adopted in our work, as it provides a strategic method to handle network traffic and load balancing efficiently.

The study in [26] presents several concepts that closely align with our research, particularly in terms of controller load and handover delay. [26] proposes a two-tiered SDN structure, with distinct roles for Tier-1 (Dist-C) and Tier-0 (Root-C) controllers. Dist-C manages a specific wireless network domain, while Root-C handles the interconnections between different domains. One key feature of [26] is the application of an Analytical Hierarchical Process (AHP) tool for network selection based on user context. This is a more advanced approach compared to traditional handover methods that rely solely on signal strength. It also considers factors such as inclination, response time, and cost to provide a network that aligns with the user's preferences. However, this process could introduce a slight delay in network selection compared to existing methods. [26] also proposes a novel mechanism that provides information about each controller's congestion level. This information guides the handover of users to less congested controllers. They categorize the load level of a controller into three states: Under-Loaded (UL), Normally-Loaded (NL), and Over-Loaded (OL). This mechanism, supported by a monitoring module that collects global and local data from Root-C and Dist-C respectively, allows load balancing by handing over users from an NL state controller to a UL state controller. Furthermore, [26] introduces a Network Selection module in Root-C that allows users to select from various pre-set candidate networks when a controller experiences high load. This mechanism claims to provide a shorter response time compared to other methods. In our research, we've drawn significant insights from the structure proposed in [26]. While we acknowledge the merits of their work, our aim is to further optimize the structure to manage potential delays in network selection and handle controller load more effectively. We present our novel structure and discuss its advantages in the following sections.

Dixit et al. [22] presents an architecture for switch mobility based on a dynamic multi-controller structure, named ElastiCon. This structure comprises three modules - a load measurement module, a load adaptation decision-making module, and an action module. These work in harmony to ensure a balanced load among the controllers. Specifically, ElastiCon measures the load of each controller periodically in real time to detect any imbalance. If an imbalance is detected, it readjusts the switch on the informed controller to balance the load between controllers. This ensures predictable controller performance even in highly dynamic operating environments. The insights from [22] are invaluable for our research, and we have incorporated similar ideas into our structure while optimizing it for our specific use case.

The study presented in [29] puts forward the concept of a Logically Centralized-Physically Distributed (LC-PD) structure for the controller, aiming to achieve low latency. Their primary focus is on improving the communication efficiency and quality of service (QoS) of Internet service execution in 5G mobile networks through an LC-PD control plane architecture. The authors argue that centralized controllers, by their very nature, bear a high load, thus escalating the risk for the entire network. As such, the deployment of the controller becomes a crucial factor with significant impact on network performance. In a distributed controller approach, although the controllers are physically dispersed, proper network distribution is not achieved due to the direct or indirect connections between networks of different domains. In contrast, the LC-PD structure enables central management of physically distributed controllers for each network, as each switch is connected exclusively to one controller. This approach from [29] has informed our understanding of controller deployment and its impact on network performance, and we have considered these insights while developing our structure.

Rath et al. [25] propose a scheme which focuses on optimizing the number of controllers and their mapping to SDN switches. This concept of ensuring an optimal number of controllers for efficient network management has been a key consideration in our proposed structure.

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Lastly, [24] underscores the importance of network stability, which can be enhanced through the use of multiple controllers. In the event of a controller malfunction or performance degradation, the availability of other controllers can ensure uninterrupted network operations. Furthermore, [24] highlights the significance of strategic controller placement in a limited network environment, and the need for an appropriate communication pattern to minimize synchronization costs between controllers before and after a failure. These aspects have guided our approach to controller placement and communication pattern selection in our proposed structure.

In summary, this section has provided an overview of various proposed methods and architectures in the literature, focusing particularly on those that seek to optimize controller load and reduce handover delay in SDN domains. These studies have offered valuable insights and formed the foundational knowledge upon which we have built our proposed structure. In the next section, we will present our proposed network architecture and provide a detailed numerical analysis to demonstrate its efficiency and effectiveness in managing controller load and minimizing handover delay.

3. DESIGN OF MULTI-CONTROLLER ARCHITECTURE

Through the network architecture based on SDN, the existing network architecture can have more flexible and highly scalable. Still, there is a lack of scalability and load balancing through a single-controller. The proposed architecture for solving these problems is shown in Figure 1.

The proposed hierarchical multi-controller architecture performs fewer tasks than the role of the local controller in normal hierarchical architecture, and the global controller performs more tasks. First, the role of the global controller is performed on the management or information sharing of local controllers. And the local controller only manages its own area switch and does not know the information of other local controllers. The advantage of this architecture is that it can move with low latency when the User Equipment (UE) moves within the

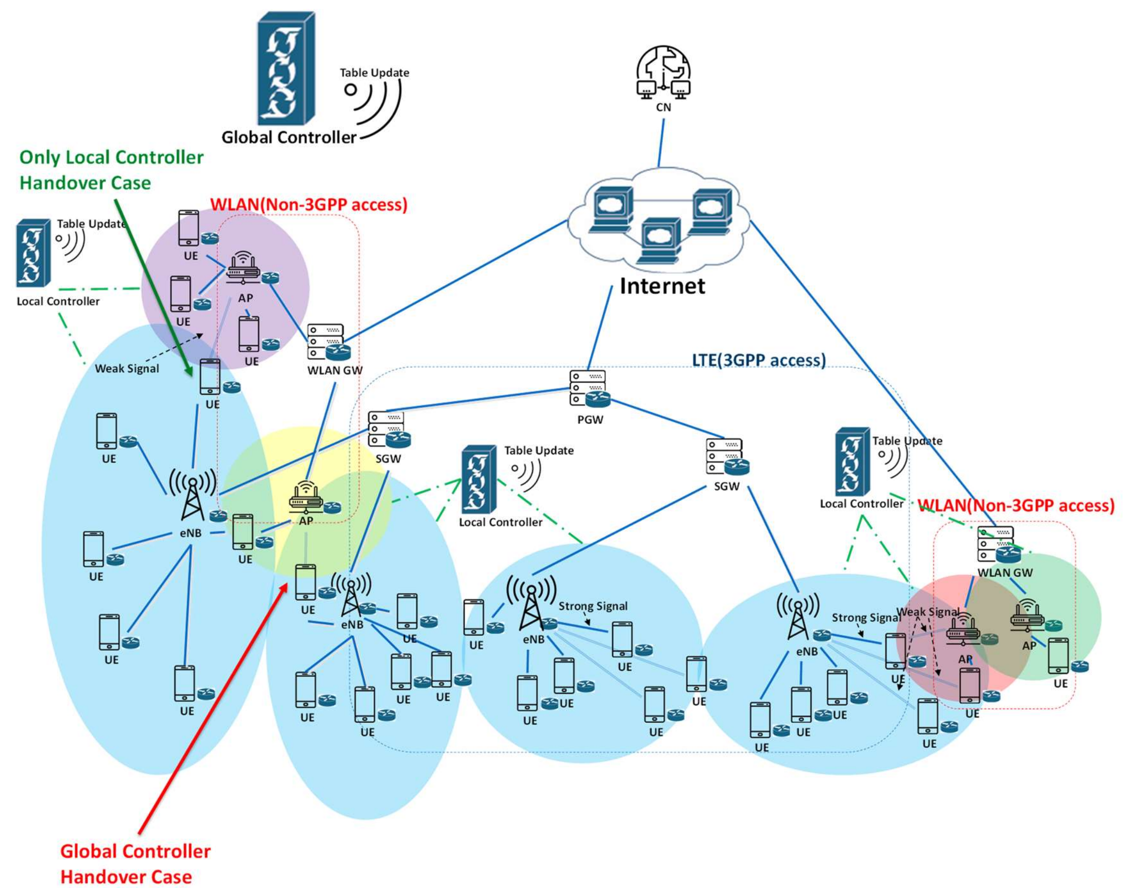

Figure 1: LTE and WiFi interworking architecture with loosely-coupled connections with multi-controllers.

local controller area due to the Local controller located at a low position.

There are two handover methods to consider when using the proposed architecture. One is handover using only the local controller, and the other is when using a global controller.

4. NUMERICAL ANALYSIS

4.1 Analysis of handover costs from LTE to WiFi

In this paper, we propose and analyze various network structures to optimize handover processes in wireless communication systems. The network structures we consider include traditional structure (T_s), single-controller (SC_s), and multi-controller (MC_s). Our aim is to compare the handover costs of these different structures and provide insights into their respective performance in terms of message exchanges. We assume that the handover probability operates based on the Poisson distribution. This is a common model for the occurrence of independent events at a constant average rate. This is particularly suitable for modeling handovers, which are independent events occurring within certain time intervals. Using the Poisson distribution allows us to accurately model and analyze the stochastic nature of handovers in wireless communication systems.

Based on this assumption, we propose Equation (1), which captures this meaning.

$$P(\lambda) = \frac{\lambda^k e^{-\lambda}}{k!} \qquad (1)$$

In Equation (1), k represents the number of handovers occurring within a specified time interval, and λ represents the handover rate measured in handovers per unit time. The Poisson distribution enables us to model the occurrence of handovers as a stochastic process.

For the traditional structure (T_s), the handover cost analysis of handovers from LTE to WiFi in traditional structure is calculated as follows Equation (2):

$$C(\lambda, T_s) = P(\lambda) \cdot H_m(T_s) \qquad (2)$$

Here, $H_m(T_s)$ denotes the number of messages required for a handover in the traditional structure. Figure 2, which is based on the [5], shows a detailed step-by-step process of a handover from LTE to WiFi in the traditional structure. Each arrow in the figure represents a distinct message that is sent or received during the handover process. This gives us a clear visual representation of the entire handover process, allowing us to count the exact number of messages exchanged. By analyzing Figure 2, we can see that the total number of messages required for a handover in the traditional structure is 11. This value corresponds to the number of arrows shown in the figure, which represents the number of messages exchanged during the handover process. Therefore, we can substitute $H_m(T_s) = 11$ in Equation (2) to calculate the handover cost for the traditional Structure. Using this figure, we can systematically count the number of messages involved in the process. By incorporating this value into Equation (2), we can accurately compute the handover cost for the traditional structure.

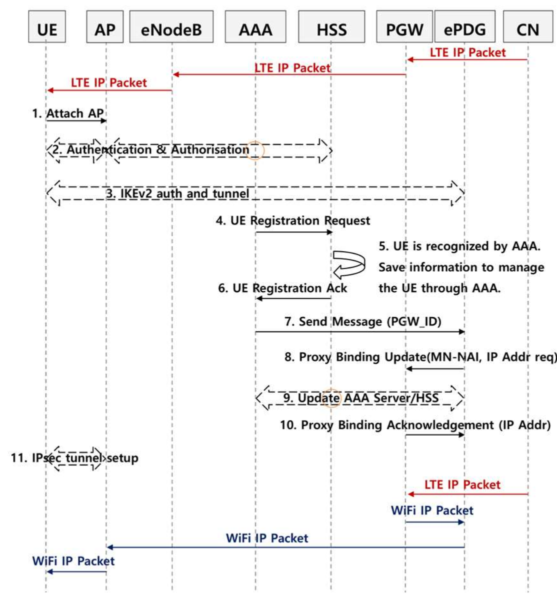

Figure 2 : The Procedure Of Handover From LTE To Wifi In Traditional Structure.

For the single-controller(SC_s), the handover cost is calculated using Equation (3):

$$C(\lambda, SC_s) = P(\lambda) \cdot H_m(SC_s) \qquad (3)$$

Figure 3, which is based on our previous work in reference [27][28], shows the process of a handover in the SC_s structure. Each arrow in the figure represents a distinct message that is sent or received during the handover process. Counting these arrows, we find that the total number of messages exchanged during a handover in the single-controller structure is 7. This value corresponds to $H_m(SC_s)$ in Equation (3).

In the single-controller structure, packets flow through the Internet due to the loosely-coupled

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architecture. IP continuity, which is typically not applicable in the common loosely-coupled architecture in the traditional structure, is effectively managed in the single-controller structure through the use of an SDN controller. This controller simplifies the authentication process and modifies the packet transmission path, resulting in more efficient handovers.

For the multi-controller(MC_s), the handover cost calculation depends on the probability of using inter-domain handovers, represented by P_{Inter} This probability is essential because it helps determine the utilization of the global controller in the MC_s. The relationship between P_{Inter} and P_{Intra} is defined by Equation (4).

$$P_{Inter} = 1 - P_{intra} \tag{4}$$

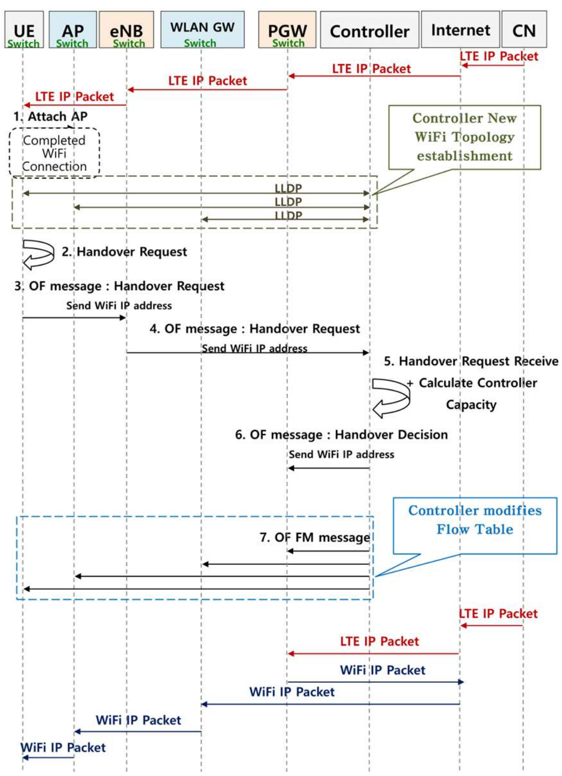

Figure 3 : The Procedure Of Handover From LTE To Wifi In Single-Controller Structure.

$C(\lambda, P_{inter}, MC_s)$ is the optimal handover cost for the multi-controller structure. The probability of inter-domain and intra-domain handovers are represented by P_{Inter} and P_{intra} , respectively. P_{Intra} represents the probability of handovers without a global controller, while P_{inter} represents the probability of handovers using the global controller.

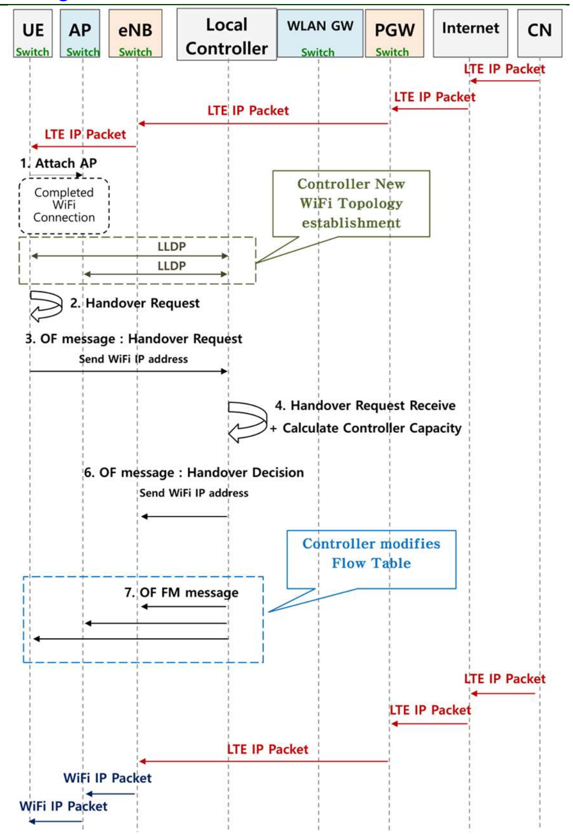

Figure 4 : The Procedure Of Handover From LTE To Wifi Without A Global Controller In Multi-Controller Structure.

In the case of multi-controller, handover using without global controllers and handover using global controllers have different numbers of messages. If you look at Figure 4, can see that using one controller is like a single-controller. However, the difference from a single-controller is that it is the location of the local controller and the information it has. Figure 4, which is based on our previous work in reference [23], shows the process of a handover in the MC_s structure. In a multi-controller, the local controller exists in a lower position than the existing single-controller. Handover between interfaces in the area covered by the local controller is possible without the intervention of the global controller. That's why it has a lower number of messages than a single-controller. When the probability of inter-domain handovers (P_{Inter}) is 0, it means that all handovers occur within the coverage area of a local controller without involving the global controller. In this case, the handover cost for the multi-controller structure is represented by $H_m(P_{inter}=0, MC_s)$, which is equal to 6, as all handovers occur locally without the need for global coordination. On the other hand, when the probability of inter-domain handovers is 100, it

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means that all handovers involve the global controller, resulting in a higher number of messages being exchanged during the handover process. In this case, the handover cost for the multi-controller structure is represented by $H_m(P_{\text{inter}}{=}100, MC_s)$, which is equal to 8, as more messages are exchanged during the handover process due to the involvement of the global controller. The above can be easily expressed with Equation (5).

$$H_m(P_{\text{inter}}, MC_s) = (1 - P_{\text{inter}}) \cdot 6 + P_{\text{inter}} \cdot 8 \quad (5)$$

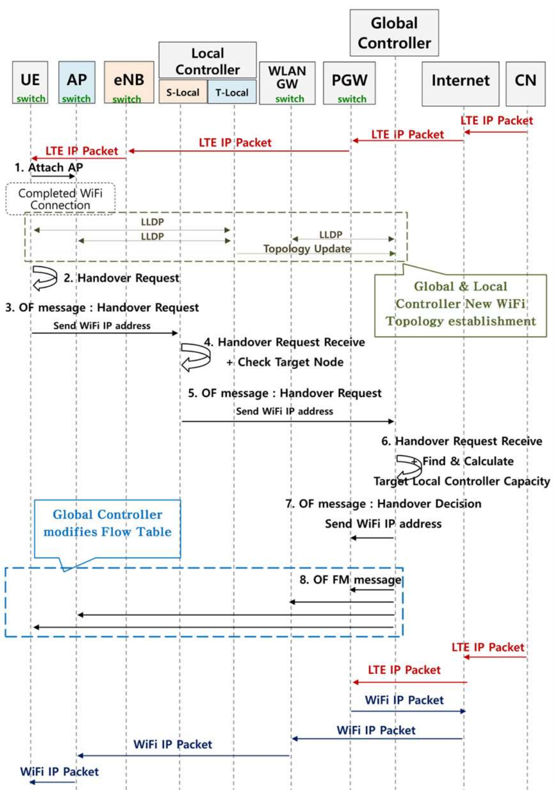

Figure 5 : The Procedure Of Handover From LTE To Wifi With A Global Controller In Multi-Controller Structure.

As shown in Figure 5, using a global controller in multi-controller counts higher than a single-controller. However, this is not considering that the current structure is a multi-controller structure. Due to the increased number of local controllers, the amount of control messages is greatly reduced per controller. In addition, most handovers do not require a global controller, multi-controller has better overall performance than single-controller in the proposed architecture. Calculate the $C(\lambda, P_{\text{inter}}, MC_s)$ using the following Equation (6).

$$C(\lambda, P_{\text{inter}}, MC_s) = P(\lambda) \cdot H_m(P_{\text{inter}}, MC_s) \quad (6)$$

It's important to note that the optimal handover cost for the multi-controller structure, $C(\lambda, P_{\text{inter}}, MC_s)$, can vary depending on the values of P_{inter} and other factors such as the network topology and traffic patterns. Therefore, it's essential to perform a thorough analysis and evaluation of the handover costs associated with different network structures to identify the most efficient solution for a specific scenario. This information can then be used to develop more effective handover mechanisms in future wireless communication systems.

4.2 Analysis of handover delay from LTE to WiFi

Handover delay calculations are also calculated based on the number of messages used in each architecture. $d_{x,y}$ is the result of calculating the delay it takes when packets heading to x return via y after the path has been changed due to the control message. The packet is transmitted over the original path and then the packet is sent after the path is modified. The shorter the return path, the lower the delay. When using ePDG in traditional architecture, the time taken is calculated as shown in the following Equation (7).

$$D(T_s) = H_m(T_s) \cdot t_{\text{unit}} + d_{\text{ue,pgw}} \quad (7)$$

$D(T_s)$ has 11 messages. And t_{unit} means the time it takes for each message to be transmitted and is assumed to be 2ms. $d_{\text{ue,pgw}}$ means the time it takes for a packet to return through the PGW to the terminal and assumes 4ms. The $D(T_s)$, Equation (8) that calculates the latency of a single-controller, is calculated in the same way as Equation (7) and $H_m(T_s)$ is the number of messages that occur when changing from LTE to WiFi.

$$D(T_s) = H_m(T_s) \cdot t_{\text{unit}} + d_{\text{ue,pgw}} \quad (8)$$

In the case of the following multi-controller, the probabilities P_{Inter} and P_{Intra}, which were previously used in cost calculations, are used. The delay generated when only the local controller is used is calculated as shown in Equation (9).

$$A = (H_m(P_{\text{inter}}{=}0, MC_s) \cdot t_{\text{unit}} + d_{\text{ue,enb}}) \cdot P_{\text{Intra}} \quad (9)$$

And when using the global controller, the delay is also expressed as in Equation (10).

$$B = (H_m(P_{\text{inter}}{=}100, MC_s) \cdot t_{\text{unit}} + d_{\text{ue,pgw}}) \cdot P_{\text{Inter}} \quad (10)$$

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Adding Equation (9) and (10), the overall delay is calculated in Equation (11) in a multi-controller environment.

$$\mathrm{D}(MC_s) = \mathrm{A}+\mathrm{B} \quad (11)$$

$d_{ue,enb}$ is the time when the UE returns through the eNB, and since it is a very short distance, it is assumed to be 2ms.

5. NUMERICAL RESULTS

In this section, we aim to analyze the cost and delay associated with our proposed procedure, which provides a precise handover process, and compare it with the results of the study described in paper [26]. While paper [26] does not provide an exact procedure, necessitating some guesswork, we base our comparison on the structure described within it, starting from the assumption that the basic handover procedure is the same as the one presented in our paper. Paper [26] outlines different handover schemes for three states: Under_Loaded (UL), Normally_Loaded (NL), and Over_Loaded (OL).

In the UL state, the network load is relatively low, and there is no significant congestion. Consequently, the intervention of the global controller is not required for handovers, as the local controllers can manage the handovers effectively. In the NL state, the network load is moderate, and some parts of the network may experience congestion. The global controller starts to intervene in handovers to maintain load balancing and minimize handover delays. The global controller may redirect the handovers to less congested areas, optimizing the network's performance. In the OL state, the network load is high, and several areas of the network experience congestion. The global controller plays a more significant role in managing handovers and load balancing. The global controller takes control of the handover process, redistributing the load across the network to reduce congestion and handover delays. We can see that the structure they propose is also strongly influenced by the degree of involvement of the global controller.

Figure 6 was generated based on educated assumptions using the flowchart provided in paper [26] for the OL, NL, and UL states. It demonstrates that the OL state has the highest number of handover messages (13), while the UL state has the fewest (6). The number of handover messages can be described by Equation (12), which focuses only on the OL state, but the NL state follows a similar pattern. Of course, when in the NL state, it has 9 messages. This will be further elaborated below:

$$H_m(P_{\mathrm{inter}}, OL_s) = (1 - P_{\mathrm{inter}}) \cdot 6 + P_{\mathrm{inter}} \cdot 13 \quad (12)$$

The intervention of the global controller in the handover process is adapted based on the network load, ensuring efficient resource utilization and network performance. For the OL states proposed in paper [26], the handover cost can be calculated using the Equation (13):

$$C(\lambda, P_{\mathrm{inter}}, OL_s) = P(k, \lambda) \cdot H_m(P_{\mathrm{inter}}, OL_s) \quad (13)$$

The proposed method calculates the delay based on the OL state, but the same approach can be applied to the NL state. This is similar to the multi-controller structure discussed earlier, with the difference being the number of messages involved. Consequently, we require two equations: one for when P_{inter} is 0 and another for when it is 100.

First, the calculation for when P_{inter} is 0 follows Equation (14).

$$\mathrm{C} = (H_m(P_{\mathrm{inter}}{=}0, OL_s) \cdot \mathrm{t}_{\mathrm{unit}} + \mathrm{d}_{\mathrm{ue,enb}}) \cdot \mathrm{P}_{\mathrm{Intra}} \quad (14)$$

And when P_{inter} is 100, it is like the Equation (15) below.

$$\mathrm{D} = (H_m(P_{\mathrm{inter}}{=}100, OL_s) \cdot \mathrm{t}_{\mathrm{unit}} + \mathrm{d}_{\mathrm{ue,pgw}}) \cdot \mathrm{P}_{\mathrm{Inter}} \quad (15)$$

Finally, by adding the two formulas together, we obtain the delay in the OL state as shown in Equation (16):

$$\mathrm{D}(OL_s) = \mathrm{C}+\mathrm{D} \quad (16)$$

We will discuss the impact of varying the inter-domain handover probability (P_{inter}) on the handover cost and delay for the three states proposed in paper [26]. Increasing P_{inter} implies a higher reliance on the global controller during handovers. This concept is analogous to the multi-controller architecture that we have proposed in our study. By comparing our proposed multi-controller structure to the states in paper [26], we can analyze the similarities and differences in handover cost and performance based on the varying degrees of global controller intervention (as indicated by the P_{inter} values).

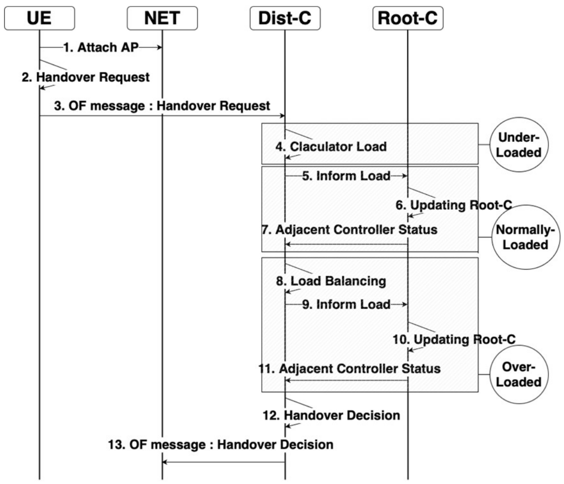

Figure 6 : A Handover Procedure Based On [26].

5.1 Analysis results of handover cost from LTE to WiFi

Figure 7 in your paper provides a detailed comparison of handover costs across different network structures, considering the impact of varying P_{inter} values (0, 0.33, 0.5, and 1) on the handover costs for each structure. The parameter λ is a crucial factor in determining handover costs, and the figure consists of four subplots, each representing one of the different P_{inter} values. When P_{inter} is 0, the traditional structure exhibits the highest handover cost. In this case, the existing structure and the single controller are not affected by the value of P_{inter} value because they are structures that do not use a global controller, as described earlier. The multi-controller structure we propose, and the NL and OL states have the same handover cost values in this scenario. When P_{inter} is 0.33, the handover cost is higher for the OL state compared to the single controller network. However, for the NL state, the handover cost is the same as for single controller networks. Despite these differences, the multi-controller architecture still generally results in lower handover costs compared to the single controller network. For P_{inter} = 0.5, the handover costs of both single and multi-controller networks are the same, indicating that structural changes through the global controller in the handover process do not necessarily lower costs. As P_{inter} increases to 1, the handover cost for the OL state becomes higher than that of the traditional structure, which indicates that an excessive reliance on the global controller can lead to higher handover costs. This finding highlights the importance of carefully managing the level of global controller intervention to maintain an efficient balance between handover costs and network performance. This means that the majority of structures are structurally better off without a global controller. However, we should consider that in the general case, the majority of users will be doing handovers locally in the majority of cases, which is why our proposed multi-controller structure is beneficial. In addition, by understanding the relationships between P_{inter} values, λ, and the performance of various network structures, we can better appreciate the impact of P_{inter} values on network performance and make more informed decisions when designing and managing network structures.

5.2 Analysis results of handover delay from LTE to WiFi

Figure 8 shows the delay taken during handover from LTE to WiFi by network architecture. This graph calculates the latency based on the percentage of time the global controller is used. The traditional architecture has a handover delay of 26ms and a single-controller has 18ms. multi-controller has the

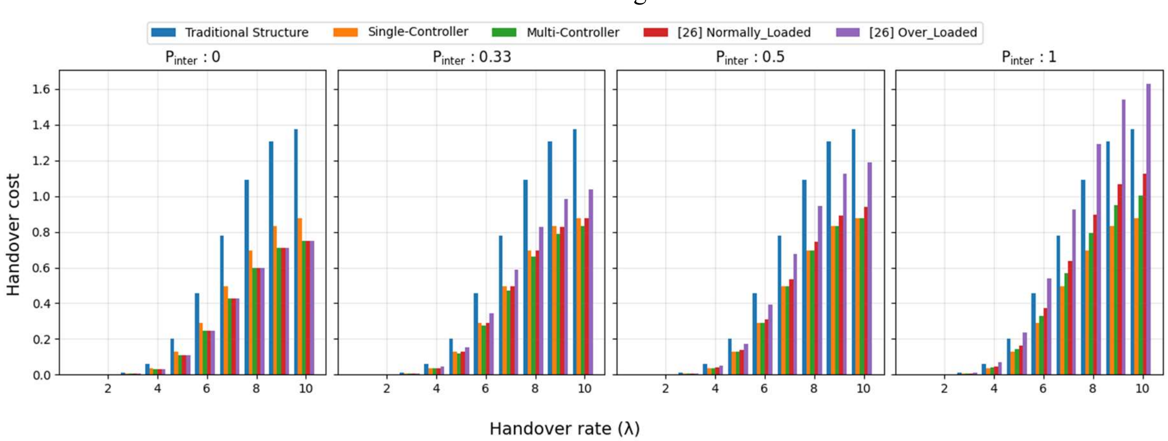

Figure 7: Handover Cost Comparison Of Various Network Structures With Different P_{Inter} Values (K=10).

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lowest latency 14ms and the longest of 20ms that is longer than a single-controller. When the usage rate of the global-controller is 67%, the handover delay is 18ms, which is the same as the delay of a single controller. In the case of OL in [26], latency of up to 30ms is introduced, which is higher than the standard structure. And in most cases, the latency is higher than a single controller, which means that in the case of OL, it is structurally better to use a single controller in terms of latency. However, if you use NL or the structure proposed in this paper, you can basically have lower latency than a single controller and have a seamless handover.

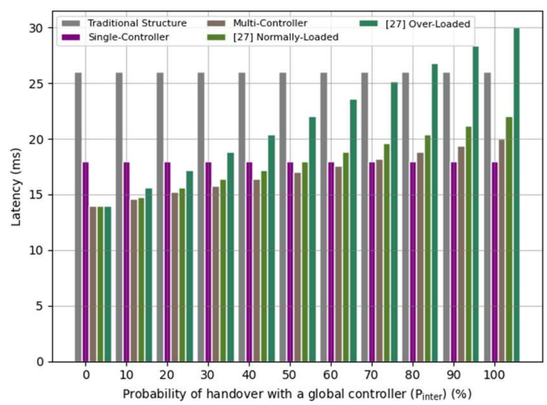

Figure 8 : Delay For Handover From LTE To Wifi.

6. CONCLUSION

In this paper, we presented an architecture that evolved from a single-controller to Multi-controller by considering the controller in-depth. Compared to a single-controller, Multi-controllers can distribute the control messages of the UE and provide a faster response and lower handover costs. This advantage arises from the fact that the local controller can manage only a small area network and has a low location. Through numerical analysis based on the loosely-coupled handover procedure, we confirmed that multi-controller generally shows better performance than the existing architecture. In addition, this paper revealed that there are structural improvements through numerical comparison and interpretation of the structure proposed by other papers. Our proposed architecture addresses the limitations of the traditional single-controller architecture and overcomes the challenges of load balancing and handover delays. We proposed a formula for calculating handover cost, taking into account the inter-domain handover probability (P_{inter}). Through numerical analysis, we found that the proposed multi-controller structure generally outperforms the traditional single-controller architecture, except for network environments that use more than 50% of global controller. In conclusion, our proposed multi-controller architecture provides a faster response and lower handover costs compared to the existing architecture. Despite the promising results, we acknowledge that this study is limited by its reliance on numerical analysis. Real-world network environments are more complex and variable, and these factors may influence the performance of the proposed architecture. Furthermore, the proposed architecture's performance in larger scale network environments and under different network conditions remains an open question. Future research should focus on these areas to further validate and refine our architecture.

As a next step, we aim to simulate our proposed solution in real network settings, which will provide more robust evidence of its effectiveness. Further exploration of the potential benefits of the multi-controller architecture in different network environments is also warranted. In addition, we plan to investigate other potential applications of our architecture, such as its use in 5G or beyond 5G networks.

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