A Cross-Layer Media-Independent Handover Scheme in Heterogeneous WiMAX/WiFi Networks

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Abstract: The main challenges in the development of future wireless communication systems are provisioning various services across different radio access technologies to mobile users with satisfactory quality of services. However, as a mobile user moves across network boundaries, the seamless service over heterogeneous networks would be an important concern. To minimize the disruption to the ongoing session while a mobile user is moving from one access network to another, we propose a framework that integrates IEEE 802.11 WLANs and IEEE 802.16 WMANs based on the IEEE 802.21, also called Media Independent Handover (MIH), to facilitate both homogeneous and heterogeneous handovers. Performance evaluation and comparisons have been done through both mathematical analysis and simulation on ns-2 simulator.

1 Introduction

The integration of heterogeneous networks is an important issue for next generation (i.e. 4G) networks, which allow mobile users to use always best connect (ABC) session through heterogeneous networks [GJ03]. The QoS mapping should be concerned in the network integration aspect due to various QoS definitions. Also, to achieve seamless mobility, the handover latency that may impact the QoS should be taken care first.

There are horizontal handover and vertical handover. Vertical handover can be classified into make-before-break and break-before-make, called soft handover and hard handover, respectively. In the former, user traffic flows are continuously available during handover period. While in the latter, the services may be disrupted for short duration. Our goal is to support seamless mobility and ensures that the ongoing session won't be disrupted during handover by reducing both handover latency and service disruption time (SDT). The former is the time elapsed from the start to the completion of a handover. The latter is the time period during which the MN is unable to receive packets. If SDT is too long, the service may be terminated.

The media-independent handover (MIH) framework defined under IEEE 802.21 assists integrating IEEE 802 and non-IEEE 802 access technologies and enables seamless mobility in 4G environments. It helps integrate WiFi and WiMAX, so as to reduce handover latency and SDT. IEEE 802.21 mainly facilitates handover decision by supplying the upper layers (layer three [L3] and higher) information about L2 triggers. The L3 handover uses mobile IPv6 (MIPv6) [JPA04] to support mobility. But MIPv6 is insufficient to support time sensitive services due to the long latency of movement detection, checking uniqueness of new IP address, and binding update, hence fast MIPv6 (FMIPv6) [Ja06] and hierarchical MIP are proposed. In this article, we propose a scheme using IEEE 802.21 and FMIPv6 to support seamless mobility for 4G environment.

We organize this paper as follows. In Section 2, we present the IEEE 802.11 and 802.16 handover procedure based on the IEEE 802.21 MIH standard [MIH08]. In Section 3, we discuss our proposed scheme and perform numerical analysis. Simulation results based on ns-2 simulator are presented in Section 4. We conclude the work in Section 5.

2 Related Works

We briefly describe the services in IEEE 802.21 standard and illustrate relevance of them on the IEEE 802.21 framework, and present the handover procedure between WiMAX/WiFi networks.

2.1 Briefs of IEEE 802.21

The IEEE 802.21 unifies the diverse L2 technology-specific information to support the handover decision. The standard [MIH08] consists of three elements: MIH user, MIH function (MIHF), and Service Access Point (SAP). The MIH user is a functional entity that uses the MIHF services. The MIHF interfaces with other layers and functional planes using SAPs. In IEEE 802.21, the L2 connectivity to the network (BS/AP) is referred to as PoA. The MIHF functionality is used in Point of service (PoS) that is a network-side MIHF instance to exchange MIH messages with an MN-based MIHF.

2.2 Handover procedure on WiMAX/WiFi networks

Handover procedure includes three steps: initiation, preparation and execution. The initiation configures old devices to report measurements when specific thresholds are crossed. In preparation, the MN starts scanning for the neighbor networks and transfer QoS context to the new network. Furthermore, radio resource must be reserved in the new network. The execution includes L2 and higher layer signaling, which are beyond the scope of the standard. We present two handover approaches, one is provided in IEEE 802.21 standard, and the other is proposed in the IEEE literature. The handover procedure can be started by either a mobile node or the network. In IEEE 802.21 standard, the handover is initiated by the mobile node and both the radio involved can transmit/receive at the same time [MIH08]. It uses MIPv6 in L3 handover and spends much time on verifying unique care-of-address (NCoA). Therefore, another proposed scheme uses FMIPv6 to perform duplicate address detection (DAD) before L2 handover re-establishment in IEEE literature [Po08]. The scheme in literature interleaves the FMIPv6 signals with L2 signals in order to reduce SDT. The literature only proposed a make-before-break approach so that the MN session can benefit from seamless handover, but ignoring the FMIPv6 in reactive mode may cause session disrupt and packet lost.

2.3 Comparison of the standard and the literature approaches

We focus on handover latency and SDT. The former is defined from an MN received

MIH_Link_Going_Down.IND till the Handover_Complete message is received. The handover latency in the standard is similar to that in the literature because they both count the time elapsed for L2 and L3 handover. For the SDT, there is a special condition in the standard. When the MN finishes L3 handover and its connection with serving PoA is still active, such as make-before-break approach, the SDT is negligible. If the MN moves fast, it may cause the handover break-before-make, and the maximum SDT is the total time of both L2 and L3 handovers.

In the literature, the SDT is the duration that MN received an FBAck message from the service access router (S-AR) till it received a forwarded packet from the target access router (T-AR), which stores the tunneled packets in a buffer, as shown in Figure 1. The maximum SDT in the literature is the total time of L2 handover, FNA message transmission, and packet forwarding from the S-AR. It only illustrated that the handover is make-before-break, but it may be break-before-make handover in which the FMIPv6 is reactive and may cause packet loss. In make-before-break handover, the approach in the standard is better than the literature's approach for SDT if MN moved slowly. The FMIPv6 predictive mode uses tunnel-based mechanism and buffer to avoid packet loss.

3 Proposed Scheme

Both SDT and packet loss rate are important factors for seamless handover in real-time applications. We consider the influence of MN's speed in packet loss rate and the SDT. The overlap distance between serving PoA and target PoA is also considered. In [Mu07] [An06] [SC07] [LSP08], MIH services are used to improve the SDT to offer the 4G always best connected vision. Our intention is providing seamless handover in either low or high speed movement. We proposed a scheme for handover in WiMAX/WiFi heterogeneous networks, our scheme includes three mechanisms that can reduce the SDT as well as achieve seamless handover in heterogeneous WiMAX/WiFi networks.

3.1 Proposed handover procedure

Our proposed scheme is presented in Figure 1 and its difference from the literature approach is marked in red. Our three mechanisms to reduce the SDT include pre-DAD procedure, parallel handover, and buffer mechanism, which are explained as follows.

Pre-DAD procedure

The DAD execution time takes at least one second. It causes L3 handover much longer than L2 handover. However, we observed that the time elapsed from the MN's receiving an MIH_Link_Detected.IND event till the trigger by MIH_Link_Going_Down.IND is dependent of the MN's speed and overlap distance between the serving PoA and the target PoA. In general, this time is longer than the duration from that MN received a MIH_Link_Going_Down.IND event till the service disruption. Therefore, we try to start DAD process before receiving a MIH_Link_Going_Down.IND event by using a mechanism called pre-DAD procedure. When the MN detects a new link, it can query the MIIS (Media Independent Information Service) about the new PoA information and forward the interface address to the S-AR by Pre-DAD.IND messages. Upon receiving the message from the MN, the S-AR replied a Pre-DAD.ACK message and configured a new IPv6 address for the MN with all S-AR neighbor network prefixes. Since address configuration can be stateless [TN98] or stateful [Bo01] in IPv6 networks, the S-AR can assist the MN to generate a new stateful IPv6 address configuration. The 128 bits IPv6 address can be configured in a 64-bit suffix combined with the new network prefix. The S-AR configures a number of NCoAs depending on the number of AR's neighbors, these NCoAs' addresses are stored in the S-AR and the AR's neighbors. The S-AR configures NCoAs with the new network prefix based on either the interface address from the MN or a randomly generated address. Moreover, these NCoAs must be confirmed with DAD procedure and stored both in the S-AR and the corresponding T-AR.

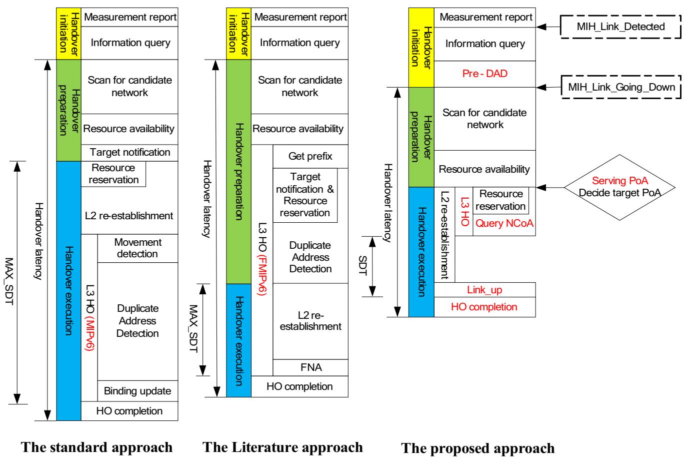

Figure 1: Comparison of three approaches

Parallel handover

The L2 and L3 handover may occur in parallel. When an MIH user knows the target PoA, it can instruct target interface of the MN to perform L2 handover procedure and send a Query_NCOA.REQ message to the S-AR through the MN interface in order to do partial L3 handover. The Query_NCoA.REQ message includes target PoA information to inform the S-AR that the MN intends to handover under its PoA and applies for NCoA. Since the L2 handover can be simultaneously executed with the partial L3 handover, we only select the longer L2 handover process to calculate the latency.

Buffer mechanism

When the S-AR receives a Query_NCoA.REQ message from the MN, the S-AR assigns an NCoA to the MN based on target PoA of the MN and establishes a tunnel between the current CoA of the MN and its NCoA at the T-AR. The T-AR intercepts the tunneled packets and stores them in a buffer until it receives a Link_Up.IND message. Then the T-AR replies a Link_Up.Ack message to the target PoA and forwards the buffered packets to the MN. Our proposed scheme is illustrated in Figure 2. It uses FMIPv6 in the L3 handover procedure. The MIH messages are depicted by solid lines, while FMIPv6 and technology-specific messages are indicated by dashed and dotted lines, respectively.

3.2 Mathematical analysis

Table 1 shows parameters for performance analysis of three approaches, $RTT_{MN\text{-}TAR}$ and $RTT_{MN\text{-}SAR}$ values are depending on whether the MN is in WiMAX or in WiFi network, other parameters are referred to [HNIST]. Note that the handover latency is the total time of handover preparation and handover execution. It could be expressed in equation (1).

$$T_{HO\_Latency} = T_{HO\_pre} + T_{HO\_exe} \quad (1)$$

The MIPv6 consists of three operations: movement detection, DAD process and binding update. In movement detection, the MN uses MIH mechanism to detect movement through L2 trigger events, and get the network prefix by exchanging Router Solicitation/Router Advertisement messages with T-AR. In DAD process, the MN sends neighbor solicitation message to its NCoA and waits at least one second for a response. The MN performs binding update by informing its home agent (HA) and correspondent node (CN) of its new location. The time for MIPv6 can be expressed as equation (2).

$$\begin{aligned} T_{MIPv6} &= T_{RS/RA} + T_{NS} + T_{DAD} + T_{BU} \\ &= T_{DAD} + 3RTT_{MN-TAR} + RTT_{TAR-HA} \end{aligned} \quad (2)$$

Before the DAD process, the MN exchanges FBU/FBAck with the S-AR, and HI/HAck with the T-AR to perform DAD process. When the MN completed L2 handover, it sends a FNA message to the T-AR for forwarding packets from the T-AR. Then, the time for FMIPv6 can be expressed in equation (3).

$$\begin{aligned} T_{FMIPv6} &= T_{RtSolPr/PrRtAdv} + T_{FBU} + T_{HI/HAck} + T_{DAD} + T_{FBAck} + T_{FNA} \\ &= T_{DAD} + 2RTT_{MN-SAR} + RTT_{SAR-TAR} + RTT_{MN-TAR} \end{aligned} \quad (3)$$

Next, we have two kinds of handover conditions, WiMAX → WiFi and WiFi → WiMAX. We analyze the handover latency of three approaches individually.

WiMAX → WiFi

Based on the values in Table 1, we can calculate equation (2) and (3) as follows.

$$T_{MIPv6} = T_{DAD} + 3RTT_{MN-TAR} + RTT_{TAR-HA} = 1022_{(ms)}$$
$$T_{FMIPv6} = T_{DAD} + 2RTT_{MN-SAR} + RTT_{SAR-TAR} + RTT_{MN-TAR} = 1034_{(ms)}$$

Specifically, T_{FMIPv6} is larger than T_{MIPv6} for few milliseconds because the MIPv6 is executed in WiFi network and the FMIPv6 is done in WiMAX network. The handover latency involves operations such as scan, resource availability check, and target notification. We can calculate the handover latency of three schemes based on Figure 1. In our scheme, we calculate the time of the L2 re-establishment instead of the time of partial L3 handover process in handover execution. In Link_Up process, it comprises the time of sending Link_Up.IND/ACK messages and forwarding packet from the T-AR to the MN. The handover latency based on equation (1) can be calculated as follows:

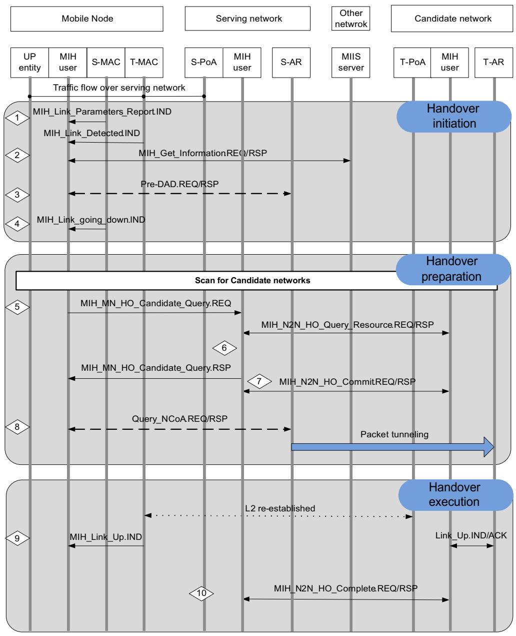

Figure 2: The proposed message flow in WiMAX/WiFi networks

Parameter	Value (ms)	Description
Tframe	5	Frame duration of IEEE 802.16e PHY
Tscan_WiMAX	85	Scan for 802.16 candidate network
Tscan_WiFi	140	Scan for 802.11 candidate network
TWiMAX_L2	287	Latency of IEEE 802.16 network re-entry procedure
TWiFi_L2	195	Latency of IEEE 802.11 network re-entry procedure
TDAD	1000	Time needed to perform a DAD process
RTTMN-TAR	--	The round-trip time between the MN and target AR
RTTMN-SAR	--	The round-trip time between the MN and serving AR
RTTTAR-HA	2	The round-trip time between target AR and home agent
RTTSAR-TAR	2	The round-trip time between serving AR and target AR

Table 1: Parameters used in mathematical analysis

$$
\begin{aligned}
T_{Standard} &= T_{HO\_pre} + T_{HO\_exe} \\
&= \left(T_{Scan\_WiFi} + \text{Resource availability} + \text{Target notification}\right) \\
&\qquad + \left(T_{WiFi_{L2}} + T_{MIPv6} + \text{Handover completion}\right) \\
&= 1373_{(ms)}
\end{aligned}
$$

$$
\begin{aligned}
T_{Literature} &= T_{HO\_pre} + T_{HO\_exe} \\
&= \left(T_{Scan\_WiFi} + \text{Resource availability}\right) \\
&\qquad + \left(T_{FMIPv6} + T_{WiFi\_L2} + \text{HO completion}\right) \\
&= 1375_{(ms)}
\end{aligned}
$$

$$\begin{aligned} T_{Proposed} &= T_{HO\_pre} + T_{HO\_exe} \\ &= (T_{Scan\_WiFi} + \text{Resource availability}) \\ &\qquad + (T_{WiFi\_L2} + \text{Link\_Up} + \text{HO completion}) \\ &= 341_{(ms)} \end{aligned}$$

WiFi → WiMAX

Similarly, we calculate equation (2) and (3) as follows:

$$T_{MIPv6} = T_{DAD} + 3RTT_{MN-TAR} + RTT_{TAR-HA} = 1040_{(ms)}$$
$$T_{FMIPv6} = T_{DAD} + 2RTT_{MN-SAR} + RTT_{SAR-TAR} + RTT_{MN-TAR} = 1026_{(ms)}$$

The handover latency based on equation (1) can be calculated as follows:

$$\begin{aligned} T_{Standard} &= T_{HO\_pre} + T_{HO\_exe} \\ &= (T_{Scan\_WiMAX} + \text{Resource availabilit} + \text{Target notification}) \\ &\qquad + (T_{WiMAX\_L2} + T_{MIPv6} + \text{Handover completion}) \\ &= 1442_{(ms)} \\ T_{Literature} &= T_{HO\_pre} + T_{HO\_exe} \\ &= (T_{Scan\_WiMAX} + \text{Resource availability}) \\ &\qquad + (T_{FMIPv6} + T_{WiMAX\_L2} + \text{Handover completion}) \\ &= 1424_{(ms)} \\ T_{Proposed} &= T_{HO\_pre} + T_{HO\_exe} \\ &= (T_{Scan\_WiMAX} + \text{Resource availability}) \\ &\qquad + (T_{WiMAX\_L2} + \text{Link}_{Up} + \text{Handover completion}) \\ &= 395_{(ms)} \end{aligned}$$

Performance comparison

Table 2 shows that our scheme outperforms other methods. Due to pre-DAD process, our scheme reduces the handover latency significantly. The L2 re-establishment is the main factor of the handover latency and the scan process is the second. The time spent for MN to handover from WiMAX to WiFi is longer than that from WiFi to WiMAX due to the L2 re-establishment and the scan process.

Handover latency (ms)	WiMAX→WiFi	Improvement	WiFi→ WiMAX	Improvement
Standard	1373	--	1442	--
Literature	1375	-0.146%	1424	1.25%
Proposed	341	75.16%	395	72.61%

Table 2: Theoretical performance comparison

4 Simulation Results

We use ns-2 (version 2.29) [HISI] with UDP traffic to evaluate the performance of our proposed scheme. We use two scenarios. In scenario I, the MN moves from WiMAX to WiFi network. While in scenario II, it redirects from WiFi to WiMAX network.

4.1 Moving from WiMAX to WiFi

We evaluate the handover performance of a mobile node (MN) and use a network topology as shown in Figure 3. In Figure 3 each wired link features 100Mbps bandwidth, 1 ms propagation delay and drop tail queuing policy. The WiMAX cell is overlapped with the coverage area of WiFi AP. It is assumed that the MN has two interfaces and connected to WMAN before it moves through the WLAN coverage area. The simulation time is 110 seconds, and at 9th second we added constant bit rate (CBR) traffic sent from the CN to the MN. The MN starts to move at 10th second with speed 10 meter per second. For CBR traffic, we use VoIP and streaming video to do experiment and check the received sequence number by the MN, we can observe which packet is delivered successfully and which one gets lost. Parameters of the simulation are listed in Table 3.

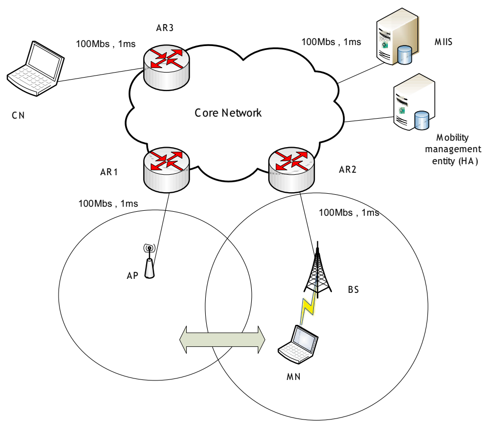

Figure 3: Simulation Network topology

Numerical results

In Figure 4(a) to Figure 4(c) we use VoIP traffic to check the received sequence number sent from CN with MN moving at 10 m/s. In Figure 4(a), horizontal axis and vertical axis represents the SDT and the packet loss, respectively. The handover begins at about 94.53s and at about 95s, the MN service is disrupted before WiFi connection established. The SDT is about 903.03ms. During the SDT, packets sent to MN got lost because no mechanism is available to buffer and forward those packets. Hence, the packet loss rate is high. In Figure 4(b), the method of literature is used. The MN moves at 10 m/s, it results in that MN can neither receive FBAck message in time nor perform the handover procedure in FMIPv6 reactive mode. Therefore, when MN finished L2 reestablishment of WiFi interface, it must send an FNA message to T-AR with an encapsulated FBU message and complete the DAD process. The SDT started at 95s and ended at 96.2s, so the total SDT is 1206.79ms. In Figure 4(c), our scheme is used. The T-AR forwards the buffered packets to the MN, which received Query_NCoA.RSP message and the forwarded packets at about 94.66s and 94.86s, respectively, and the total SDT is 195.38ms. In Table 4, we compare the SDT of three approaches. The SDT in our proposed approach is much lower than that in the standard.

We change the MN moving speed from 1 m/s to 30 m/s and perform simulation for every 5 m/s, and compare our proposed scheme with other two approaches. Figure 4(d) illustrates the relation between the SDT and speed. Specifically, our proposed scheme has a stable value. Because of buffer mechanism, we can store packets during the SDT and the SDT of our proposed scheme is around 195ms. The literature approach with 1 m/s of the MN speed is predictive mode and has buffer mechanism like our proposed method.

4.2 Moving from WiFi to WiMAX

The parameters of scenario II is same as that in scenario I, but the MN is under WiFi AP and handover is from WiFi to WiMAX network.

Numerical results

In Table 4, we represent the result of the MN handover from WiFi to WiMAX, it is similar to the result in scenario I. The SDT of the standard method is about 1004.634ms, the SDT of literature approach is about 1298.37ms, and it is about 289.87ms in our scheme. The SDT in our proposed scheme is improved by 71.175% comparing with the standard scheme.

Parameter	Value	Parameter		Value
Network Topology		**WiMAX Configuration**		
WiMAX cell coverage	1000meter(m)	Dcd_interval		5s
WiFi cell coverage	100m	Ucd_interval		5s
Coverage area	40m	Default modulation		OFDM_16QAM_3_4
Mobility Model		Frame duration		5 ms
Velocity	10(m/s)	**CBR traffic**		
Path	Straight line	VoIP	Packet size	200 bytes
WiFi Configuration			Data rate	64 Kbps
Data rate	11Mbps	Streaming Video	Packet size	1500 bytes
Beacon interval	0.1 s		Data rate	1 Mbps
MinChannelTime	0.02 s			
MaxChannelTime	0.06 s			

Table 3: Parameters of simulation

SDT	WiMAX→WiFi	Improve over standard	WiFi→WiMAX	Improve over standard
Standard	903.031	--	1004.634	--
Literature	1206.785	-33.64%	1298.366	-29.24%
Proposed	195.376	78.364%	289.87	71.175%

Table 4: The SDT of three approaches

5 Conclusion

In this article, we proposed three mechanisms to assist handover procedure. According to the simulation result, the handover latency and the SDT is reduced over 70% and the result features good correlation with mathematical analysis. Specifically, the literature scheme in FMIPv6 does not improve the SDT, because it changes to reactive mode when the speed of MN exceeds 5 m/s. So, it needs more time than the standard to complete handover. We use pre-DAD and parallel handover mechanism to improve the method of the literature and achieve a good performance in both handover latency and SDT.

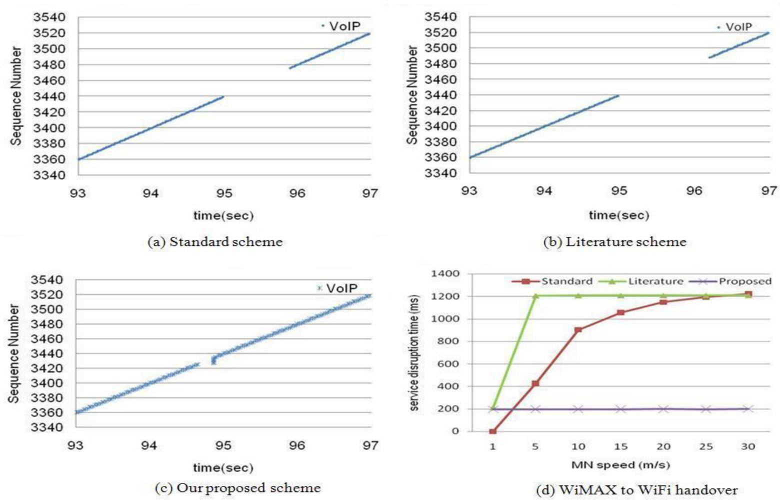

Figure 4: Simulation result

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