An Algorithm for Optimizing Vertical Handoff between WLAN and Cellular Networks

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Abstract— **Today, the advent of heterogeneous wireless networks has caused a revolution in the telecommunication systems. As IP-based wireless networking increases in popularity, the handoff issue is taken into the consideration. In the vertical handoff in which users switch between networks under different technologies, many factors should be considered in order to increase the efficiency of the network. An analytical model using absolute signal strength has been previously developed for evaluating the handoff algorithm. In this paper we designed a vertical handoff algorithm and extend that analytical model by adding two different models. The models are for handoff from Wireless Local Area Network (WLAN) to cellular network for the voice session and for handoff from cellular network to WLAN for the data session based on Received Signal Strength (RSS) and application type. Since the RSS is considered in this model, it is predicted this algorithm reduces the number of vertical handoffs.**

Index Terms—**vertical handoff-wireless local area network (WLAN), cellular network, received signal strength (RSS)**

I. INTRODUCTION

HETEROGENEOUS wireless networks consist of different Wireless Local Area Networks (WLAN), various cellular networks, and many other networks with different technologies. One of the most popular networks in 4G mobile networks is WLAN. Recently, the use of WLAN in areas such as airports, hotels and school campuses has increased. The popularity of the WLAN is mainly due to their low cost and their high data rate of 54 Mbps, where this data rate has been defined in the IEEE802.11a. However, WLAN support a small area of coverage and can support users with low mobility [1].

On the other hand, although cellular networks such as 4G networks support a higher degree of mobility and a wider area of coverage, they offer guaranteed quality of services in data transmission at a lower data rate. The complementary features of these two networks, WLAN and cellular networks make their integration highly desirable. Their integration brings a cost-effective system capable of providing ubiquitous data services, with high data rates in planned locations [2].

One of the important issues in heterogeneous wireless networks is the vertical handoff which will occur when a user switches between two different network interfaces with different technologies. For example if a mobile node leaves a 802.11b network domain and enters a 802.16 network domain, it is called a vertical handoff.

This research is significant since it provides mathematical models for calculating the probability of handoff occurring for service providers and this algorithm minimizes the number of vertical handoffs. In the next section, we briefly describe several algorithms which have been developed recently for optimizing vertical handoffs and then we will introduce our proposed algorithm.

II. BACKGROUND

Many algorithms have been developed recently in order to optimize the vertical handoff between WLAN and cellular networks. In each algorithm, different factors have been considered. For example in one algorithm, by taking system history information into account, the author reduced the number of handoffs and the cost [3]. In one of the bandwidth based algorithms, the author could reduce the Wrong Decision Probability (WDP) and balance the traffic load [4, 5]. Moreover, in some of the cost based algorithms, the author could reduce the blocking probability and increase the throughput of the system [5, 6, 7]. We were looking for a factor in order to minimize the number of handoffs and by studying the RSS based algorithms we realized these algorithms could reduce the number of handoffs. In the following section, we will briefly describe three RSS based algorithms.

A. *An Adaptive Lifetime based Handoff Heuristic Algorithm*

For handoff between 3G networks and WLAN, an algorithm was proposed in [5] by considering a life time metric which shows the application specific time period in which a user can still get services from WLAN. The algorithm

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evolves two different scenarios which will be described as follows:

First Scenario: In this scenario, a handoff from WLAN to 3G network will happen if the average RSS of a WLAN connection is less than the predefined threshold and if the lifetime is less than or equal to the handoff delay. The average RSS should be calculated continuously from the following equation [5, 8].

$$\overline{RSS}[k] = \frac{1}{Wav}\sum_{i=0}^{Wav}\overline{RSS}[k-i]$$

Here *Wav* is a variable that changes with the velocity of mobile terminal and is called window size and *k* is the time index. By using *RSS[k]*, the life time metric or *EL[k]* is calculated through the following formula [5, 8].

$$EL[k] = \frac{\overline{RSS}[k] - ASST}{S[k]}$$

The Application Signal Strength Threshold (*ASST*) depends on a composite channel bit error rate, application error resilience and application QoS requirements. The *S[k]* varies with the window size of the slope estimator and the RSS sampling interval [5, 8].

Second Scenario: In this scenario, a handoff is initiated if a mobile terminal moves from a 3G network to WLAN network. The handoff will be triggered if sufficient bandwidth is available on the WLAN network and if the threshold of a 3G network falls below the average RSS measurement of a WLAN signal [5, 8].

The author could achieve many benefits in handoff between mentioned networks. By using the lifetime metric, the number of extra handoffs will be decreased and throughput of the network will dramatically increase. Moreover, increasing the lifetime metric causes an increase in the packet delay which is the disadvantage of this algorithm. In solving this problem, the *ASST* is adjusted based on different parameters such as delay thresholds, mobile terminal velocities, handoff signaling costs and packet delay penalties [5, 8].

B. An RSS Threshold Based Dynamic Heuristic Algorithm

In this algorithm a dynamic RSS threshold (S_{dth}) is defined when a mobile terminal is connected to a WLAN access point. It is used for handoff decisions from WLAN to 3G through comparison of the current RSS and S_{dth}. By using S_{dth} in this algorithm, the number of false handoffs will be reduced and the handoff failure will be kept below a limit while the number of superfluous handoffs will remain the same [5, 9]. S_{dth} is calculated from the following formula [9].

$$S_{dth} = RSS_{\min} + 10\beta\log 10(\frac{d}{d - L_{BA}}) + \varepsilon$$

Here RSS_{min} (in dB_m) is the minimum RSS needed for the mobile terminal to communicate with an access point, β is the path loss coefficient, *d* is the side length of WLAN cell in meters. Here the assumption is that WLAN cells have a hexagonal shape in this study, L_{BA} is the shortest distance between the point at which handoff is initiated and the WLAN boundary, and ε (in dB) is a zero-mean Gaussian random variable with a standard deviation which represents the statistical variation in RSS caused by shadowing [5, 9].

The distance L_{BA} varies with the desired handoff failure probability P_f, the velocity of the mobile terminal *v*, and the handoff delay from WLAN to 3G which is shown as τ. L_{BA} calculated as follows:

$$L_{BA} = [\tau^2 v^2 + d^2(p_f - 2 + 2\sqrt{1-p_f}]^{\frac{1}{2}}$$

In this algorithm the authors assumed the failure probability from 3G to WLAN is zero, so the handoff can happen anytime a mobile terminal enters WLAN coverage [5, 9]. One of the advantages of this algorithm is that when a mobile terminal's traveling time inside a WLAN cell is less than the handoff delay, then the handoff may result in wastage of network resources [5, 9].

C. A Traveling Distance Prediction Based Algorithm

This is another RSS based algorithm in which the authors considered the time it takes for a mobile terminal to travel via a WLAN cell (t_{WLAN}) in order to reduce the number of unnecessary handoffs. In this design, a handoff will occur in a case that the traveling time is greater than the time threshold (T_{WLAN}). The traveling time (t_{WLAN}) is calculated as follows [5, 10].

$$t_{WLAN} = \frac{R^2 - {I_{os}}^2 + v^2(t_s - t_{in})^2}{v^2(t_s - t_{in})}$$

Here *R* is the radius of the WLAN cell, I_{OS} is the distance between the place where the mobile terminal takes an RSS sample and the access point, *v* is the velocity of the mobile terminal, and t_s is the time at which the RSS sample is taken, and t_{in} is the time the mobile terminal enters the WLAN cell coverage. I_{OS} can be calculated by using the RSS information and log-distance path loss model [5, 10].

The time threshold (T_{WLAN}) is calculated based on various parameters as

$$T_{WLAN} = \frac{2R}{v}\sin(\sin^{-1}(\frac{v\tau}{2R}) - \frac{\pi}{2}P)$$

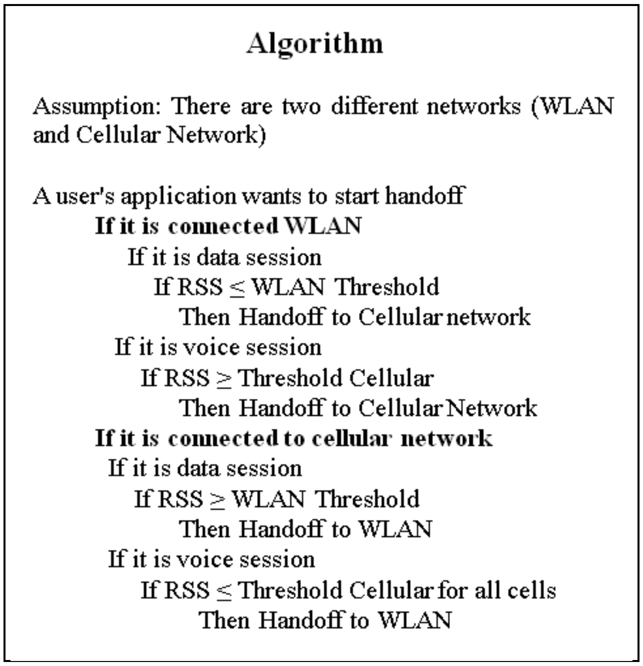
Here *P* is the maximum tolerable handoff failure, unnecessary handoff or connection breakdown probability. τ is the handoff delay. For the handoff to be initiated the WLAN RSS should fade continuously and the mobile terminal should reach a handoff commencement boundary area which size is dynamic to the mobile terminal's speed [5, 10].

While this algorithm reduces the number of extra handoffs and minimizes handoff failures, mobile terminal's traveling time is still less than the handoff delay which causes loss of network resources [5, 10]. All the RSS based algorithms mentioned above reduces the number of handoff, therefore we considered the RSS as one of the basis of our algorithm. Furthermore, we considered the application type (data and voice) in order to make a classification between different types of communications. In the following section, we will introduce our algorithm.

III. ALGORITHM DESCRIPTION

In the proposed algorithm, two different networks were considered, WLAN and cellular network. The proposed algorithm is shown in Fig. 1. The algorithm is divided into two parts:

In the first part, the user is in the WLAN and wants to initiate a handoff to a cellular network. At this time, the user checks the application type. If it is data, the user prefers to stay in the WLAN since WLAN is a good network for data applications. But if the RSS in the WLAN is less than the threshold (a certain number which can be considered as a limitation for the network in order to accept the new signal), then this signal is very weak and the user needs to initiate handoff to the cellular network. If the application type is voice, the user prefers to handoff to the cellular network since the voice applications work better in cellular networks. Therefore, if the RSS is greater than the threshold for the cellular network, the signal is very strong and works better in the cellular network. Therefore, the handoff from WLAN to the cellular network will occur.



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Algorithm

Assumption: There are two different networks (WLAN
and Cellular Network)

A user's application wants to start handoff
    If it is connected WLAN
        If it is data session
            If RSS $\leq$ WLAN Threshold
                Then Handoff to Cellular network
        If it is voice session
            If RSS $\geq$ Threshold Cellular
                Then Handoff to Cellular Network
    If it is connected to cellular network
        If it is data session
            If RSS $\geq$ WLAN Threshold
                Then Handoff to WLAN
        If it is voice session
            If RSS $\leq$ Threshold Cellular for all cells
                Then Handoff to WLAN
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Fig. 1. Our Proposed Algorithm

In the second part, the user is in a cellular network and wants to initiate a handoff to WLAN. If the application type is data, the user prefers to handoff to the WLAN. Therefore, if the RSS is greater than the threshold for the WLAN, the signal is very strong and handoff will occur. If the application type is voice, the user prefers to stay in the cellular network. However, if the RSS is less than the threshold for the cellular network, then this signal is very weak and the handoff will occur.

IV. VERTICAL HANDOFF PROBABILITY MODEL

In this algorithm, the probability functions follow a Gaussian distribution which is as follows:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp((x-\mu)^2 / 2\sigma^2) \tag{1}$$

Where the parameter σ^2 is variance, μ is the mean and $P\ (x)$ is the curve in the Gaussian distribution.

The cumulative distribution function (cdf) was also used which describes probabilities for a random variable. The cdf of the standard normal distribution is denoted by the Q and can be computed as an integral of the probability density function:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-y^2/2} dy \tag{2}$$

A. Handoff from WLAN to Cellular Network (Data Session)

If the mobile station is in the WLAN and wants to initiate a handoff to cellular network (WLAN→Cellular network), according to the algorithm, if it is a data session, the handoff will be executed if (RSS< WLAN Threshold).

The method which was used is based on what the authors in [8] and [11] did for their research which is based on Gaussian properties of the received signal strength. For calculation several terms should be defined as follows:

$\boldsymbol{P}_{c|w\ [i]}$ = the probability that in the time i the handoff occurs from WLAN to Cellular network.

RSS = received signal strength and is the basis of our algorithm.

$\boldsymbol{Thr}_{WLAN}$= the threshold of WLAN

So according to what was stated above, $P_{c|w\ [i]}$ is as follows:

$$P_{c|w\ [i]} = P\{Rss_i < Thr_{WLAN}\} \tag{3}$$

Equation (3) can be rewritten as (4), and (5). In the time i-1, the Mobile Station (MS) should be in the WLAN coverage and in that time, the RSS should be greater than Thr_{WLAN}.

$$P_{c|w\ [i]} = P\{Rss_i < Thr_{WLAN} |\ WLAN_{[i-1]}\} \tag{4}$$

$$P_{c|w\ [i]} = P\{Rss_i < Thr_{WLAN} | Rss_{i-1} > Thr_{WLAN}\} \tag{5}$$

Therefore, according to the probability formula,

$$P_{c|w\,[i]} = \frac{P\{Rss_i < Thr_{WLAN},\ Rss_{i\text{-}1} > Thr_{WLAN}\}}{P\{Rss_{i\text{-}1} > Thr_{WLAN}\}} \tag{6}$$

For simplicity, *Thr* $_{WLAN}$ is shown as t_w and (6), is rewritten as (7).

$$P_{c|w\,[i]} = \frac{P\{Rss_i < t_w,\ Rss_{i\text{-}1} > t_w\}}{P\{Rss_{i\text{-}1} > t_w\}} \tag{7}$$

The conditional probability can be computed using the Gaussian distribution [11]. The *Rss* $_{i-1}$ and *Rss* $_i$ have a Gaussian distribution so the mean and the variance are defined in the following expressions.

$$E(Rss_i) = \mu_{Rss_i} \quad VAR(RSS_i) = \sigma_{Rss} \tag{8}$$

$$E(Rss_{i\text{-}1}) = \mu_{Rss_{i\text{-}1}} \quad VAR(RSS_{i-1}) = \sigma_{Rss} \tag{9}$$

According to the definition of a Q function,

$$P\{Rss_{i\text{-}1} > t_w\} = Q\left(\frac{-t_w - \mu_{RSS_{i-1}}}{\sigma_{RSS}}\right) \tag{10}$$

The numerator of (7), is as follows [11]:

$$P\{Rss_i < t_w, Rss_{i\text{-}1} > t_w\} = \tag{11}$$

$$\int_{-\infty}^{t_w} Q\left(\frac{-t_w - \mu_{RSS_{i-1}} - \gamma(t - \mu_{RSS_{i-1}})}{\sigma_{RSS}(1-\gamma^2)}\right) \times P_{RSS_i}(t)\,dt$$

In (11), γ is the correlation coefficient between *Rss* $_{i-1}$ and *Rss* $_i$.

Here, both numerator and denominator were found. Therefore, the probability of a mobile station being in WLAN and wanting to execute a handoff to a cellular network when it receives a data session is as follows [11]:

$$P_{c|w\,[i]} = \frac{\displaystyle\int_{-\infty}^{t_w} Q\left(\frac{-t_w - \mu_{RSS_{i-1}} - \gamma(t - \mu_{RSS_{i-1}})}{\sigma_{RSS}(1-\gamma^2)}\right) \times P_{RSS_i}(t)\,dt}{Q\left(\dfrac{-t_w - \mu_{RSS_{i-1}}}{\sigma_{RSS}}\right)} \tag{12}$$

B. Handoff from WLAN to Cellular Network (Voice Session)

If the mobile station is in the WLAN and wants to initiate a handoff to cellular network (WLAN→ Cellular network), according to the algorithm, if it is voice session, the handoff will be executed if (RSS> Threshold cellular network).

$$P_{c|w\,[i]} = P\{Rss_i > Thr_{cellular}\} \tag{13}$$

Equation (13) can be rewritten as (14) and (15). In the time i-1, the MS should be in the WLAN coverage and in that time, the RSS should be greater than *Thr* $_{WLAN}$.

$$P_{c|w\,[i]} = P\{Rss_i > Thr_{cellular} | WLAN_{[i\text{-}1]}\} \tag{14}$$

$$P_{c|w\,[i]} = P\{Rss_i > Thr_{cellular} | Rss_{i\text{-}1} > Thr_{WLAN}\} \tag{15}$$

According to the probability formula,

$$P_{c|w\,[i]} = \frac{P\{Rss_i > Thr_{cellular}, Rss_{i\text{-}1} > Thr_{WLAN}\}}{P\{Rss_{i\text{-}1} > Thr_{WLAN}\}} \tag{16}$$

For simplicity, *Thr* $_{WLAN}$ is shown as t_w and *Thr* $_{cellular}$ is shown as t_c therefore, the (16), is rewritten as (17).

$$P_{c|w\,[i]} = \frac{P\{Rss_i > t_c,\ Rss_{i\text{-}1} > t_w\}}{P\{Rss_{i\text{-}1} > t_w\}} \tag{17}$$

Since the ($Rss_i > t_c$) and ($Rss_{i-1} > t_w$) are independent from each other, according to the probability function,

$$P_{c|w\,[i]} = \frac{P\{Rss_i > t_c\} \times P\{Rss_{i\text{-}1} > t_w\}}{P\{Rss_{i\text{-}1} > t_w\}} \tag{18}$$

And therefore, according to the definition of Q function,

$$P_{c|w\,[i]} = P\{Rss_i > t_c\} = Q\left(\frac{t_c - \mu_{RSS_i}}{\sigma_{RSS}}\right) \tag{19}$$

Therefore, the probability of a mobile station being in a WLAN and wanting to execute a handoff to cellular network when it receives a voice session is as follows:

$$P_{c|w\,[i]} = Q\left(\frac{t_c - \mu_{RSS_i}}{\sigma_{RSS}}\right) \tag{20}$$

C. Handoff from Cellular Network to WLAN (Data Session)

By following the same procedure, the probability of a mobile station being in a cellular network and wanting to execute a handoff to a WLAN when it receives a data session is as follows:

$$P_{w|c\,[i]} = Q\left(\frac{t_w - \mu_{RSS_i}}{\sigma_{Rss}}\right) \tag{21}$$

D. Handoff from Cellular Network to WLAN (Voice Session)

By following the same procedure the probability of a mobile station being in a cellular network and wanting to execute a handoff to a WLAN when it receives a voice session is as follows [11]:

$$P_{w|c\,[i]} = \frac{\int_{-\infty}^{t_c} Q\left(\frac{-t_c - \mu_{RSS_{i-1}} - \gamma(t-\mu_{RSS_{i-1}})}{\sigma_{RSS}\,(1-\gamma^2)}\right) \times P_{RSS_i}(t)\, dt}{Q\left(\frac{-t_c - \mu_{RSS_{i-1}}}{\sigma_{RSS}}\right)} \tag{22}$$

E. *The Probability of Handoff Occurring*

In this part, we used the same methodology as [11] for calculating the probability of handoff occurring which is based on recursive way. Therefore, those probabilities can be computed in a recursive way as follows:

$$P_{ho}[i] = P_w[i-1]\, P_{c|w}[i] + P_c[i-1] P_{w|c}[i] \tag{23}$$

Here,

$P_{ho}[i]$ = the probability that handoff occurs between a WLAN and cellular network at time i
$P_w[i-1]$ = the probability that the mobile station is in the WLAN at time i-1
$P_{c|w}[i]$ = the probability that a mobile station executes handoff from a WLAN to a Cellular network at time i
$P_c[i-1]$ = the probability that the mobile station is in the cellular network at time i-1
$P_{w|c}[i]$ = the probability that the mobile station executes handoff from cellular network to a WLAN at time i.

The following formulas also were introduced for the $P_w[i]$ and $P_c[i]$

$$P_w[i] = P_w[i-1](1 - P_{c|w}[i]) + P_c[i-1] P_{c|w}[i] \tag{24}$$

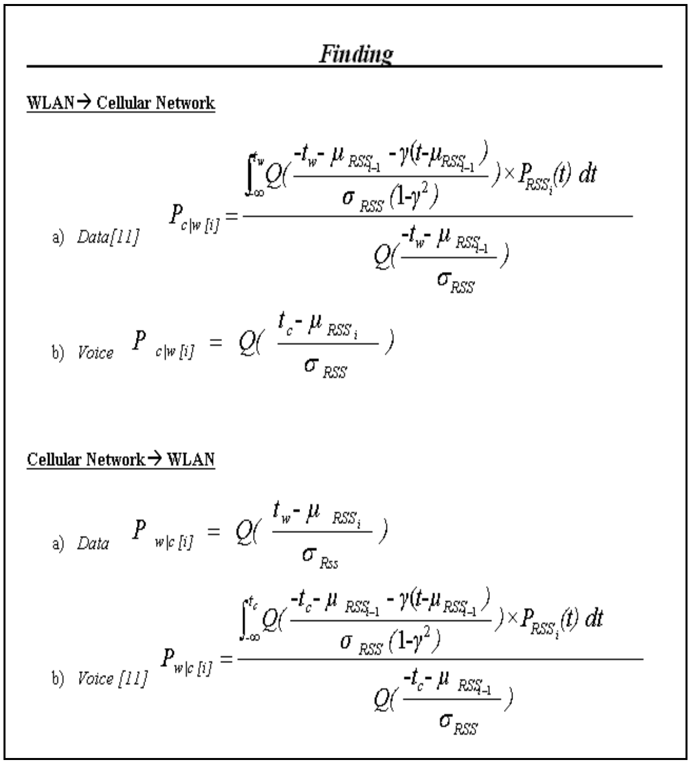
$$P_c[i] = P_c[i-1](1 - P_{w|c}[i]) + P_w[i-1] P_{w|c}[i] \tag{25}$$

V. SUMMARY

A summary of finding is shown in Fig. 2. By taking RSS and application type into consideration, the number of handoff probability is reduced.

VI. CONCLUSION

In this paper, we found the mathematical models related to vertical handoff in order to reduce the number of vertical handoffs occurring between WLAN and Cellular network. We also included the application type (data and voice) in our model to have a specific model for both data and voice sessions. The RSS was the base of our algorithm to find the models. Finally, two new mathematical models for the handoff from a WLAN to a cellular network (voice session) and for the handoff from a cellular network to a WLAN (data session) were suggested. Then, by using those formulas, the probability of handoff occurring according to a recursive model can be calculated for different value of i. Since the RSS was used in this algorithm, it is predicted this algorithm decreases the probability of occurring handoff. However, the proof and the simulation of the algorithm for both application types (data and voice) and also the proof of the probability of handoff occurring formula for a different time are considered for future works. Comparison with other WLAN/Cellular handoff mechanisms will be considered for future work.



Finding

WLAN→ Cellular Network

a) *Data[11]*

$$P_{c|w\,[i]} = \frac{\int_{\infty}^{t_w} Q\left(\frac{-t_w - \mu_{RSS_{i-1}} - \gamma(t-\mu_{RSS_{i-1}})}{\sigma_{RSS}\,(1-\gamma^2)}\right) \times P_{RSS_i}(t)\, dt}{Q\left(\frac{-t_w - \mu_{RSS_{i-1}}}{\sigma_{RSS}}\right)}$$

b) *Voice*

$$P_{c|w\,[i]} = Q\left(\frac{t_c - \mu_{RSS_i}}{\sigma_{RSS}}\right)$$

Cellular Network→ WLAN

a) *Data*

$$P_{w|c\,[i]} = Q\left(\frac{t_w - \mu_{RSS_i}}{\sigma_{Rss}}\right)$$

b) *Voice [11]*

$$P_{w|c\,[i]} = \frac{\int_{-\infty}^{t_c} Q\left(\frac{-t_c - \mu_{RSS_{i-1}} - \gamma(t-\mu_{RSS_{i-1}})}{\sigma_{RSS}\,(1-\gamma^2)}\right) \times P_{RSS_i}(t)\, dt}{Q\left(\frac{-t_c - \mu_{RSS_{i-1}}}{\sigma_{RSS}}\right)}$$

Fig.2. Summary of Finding

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