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Using fuzzy logic to reduce ping-pong handover effects in LTE networks

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Abstract Recently, mobile communications have been widely used in people's everyday lives. Their handover process facilitates people to transfer an ongoing call or a data session from one service area to another without conducting any communication interruption. However, in mobile communications, the ping-pong effect is a serious problem since it may cause unnecessary handover and lead to data loss and high computation cost. This is the case when a user equipment (UE) moves between two or among more evolved Node Bases (eNBs), due to signal strength reason, the UE in a very short time period alternatively switches among the eNBs. Consequently, the eNBs bounce the communication link the UE connected to them back and forth. Although several previous researches have been made to mitigate the ping-pong effect, what seems to be lacking is effectively eliminating unnecessary handover. Therefore, in this paper, we propose a fast and simple fuzzy-logic-based handover decision system, named *F*uzzy based Low *P*ing-Pong *E*ffect *H*andover *S*ystem (FPEHS for short), to reduce the ping-pong effect in an LTE network. In the FPEHS, five parameters, including current signal-to-noise ratio (SNR), detected SNR, bandwidth of serving eNB, bandwidth of target eNB, and remaining energy of the underlying user's device, are inputted to the fuzzy logic unit to make handover decision. Our simulation results show that the FPEHS can effectively decrease the ping-pong effect about 92.94 % in average compared with that of the standard LTE's handover mechanism.

Keywords Fuzzy · Handover · LTE · Ping-pong effect · Signal-to-noise ratio (SNR)

1 Introduction

In recent years, portable devices and wireless communications have been popularly used in people's everyday lives. A handover process which plays an important role in maintaining wireless communication quality facilitates people to transfer from one service area to another. In fact, an unsuitable handover often leads to an unnecessary handover delay (Zahran et al. 2006) and resource consumptions (Yan et al. 2008), thus declining the transmission quality.

In the past few years, several articles have been devoted to study how to smoothly hand over (Bien et al. 2010; Yan et al. 2010; Herman et al. 2013; Zhang et al. 2013) among eNBs. Bien et al. (2010) proposed a direction assisted handoff algorithm to reduce the total number of handoffs. The authors claimed that this algorithm dramatically increasing the probability of successful handoffs. Yan et al. (2010) introduced a comprehensive network mobility solution for proxy mobile IPv6 (PMIPv6) network by enabling off-the-shelf IP devices to roam within the fixed infrastructure between fixed and mobile points of attachment while using the same IP address. Herman et al. (2013) implemented an LTE handover algorithm based on Reference Signal Received Power (RSRP) measurements in which detailed modelling of RSRP measurements, including sliding window averaging, time-to-trigger and hysteresis evaluations, was considered. Zhang et al. (2013) proposed a policy-based approach to support users' mobility for heterogeneous networks. The users' mobility was supported as a trade-off among different aspects, depending on the respective administration's goals.

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Another serious problem caused by unsuitable handover decisions is that it may result in a ping-pong effect which is the case when a user equipment (UE) moves between two or among more evolved Node Bases (eNBs), due to signal strength reason, the UE in a very short time period alternatively switches among the eNBs. Consequently these eNBs bounce the communication link the UE connected to them back and forth. In a handover process, ping-pong effect that needs to be solved, since it may worsen the communication quality or even abnormally disrupt the underlying communication.

Some studies have tried to solve the ping-pong effect (Lin et al. 2013; Behjati and Cosmas 2013; Rasmussen and Oppermann 2003; Lobinger et al. 2011). Since the coordinated multipoint (CoMP) transmission and reception is the key technique enhancing cell-edge throughput in mobile communication, Lin et al. (2013) proposed a handover algorithm to support joint processing in the CoMP and overcome the system capacity limitation and ping-pong effects. Behjati and Cosmas (2013) reported an approach and strategy to plan, design, simulate, analyze and implement a self-organizing network solution over the LTE network, focusing on interfering coordination objectives and solutions. Rasmussen and Oppermann (2003) presented an analytical description of weighted linear parallel interference cancellation, which based on an eigenvalue decomposition of the correlation matrix, was used to investigate convergence characteristics with special attention toward oscillating behavior leading to ping-pong effects. Lobinger et al. (2011) stated the interactions of two self-optimizing network algorithms and showed an example of a coordination system which could be used to observe the system performance and control the algorithms. The above methods have indeed reduced ping-pong effects. However, these studies only considered one or two affected communication parameters. What seems to be lacked is the investigation of multiple parameters on this effect.

Therefore, in this paper, we propose a fast and simple fuzzy-logic-based handover decision system, named *F*uzzy based Low *P*ing-Pong *E*ffect *H*andover *S*ystem (FPEHS for short), to reduce the ping-pong effect in an LTE network. In the FPEHS, five parameters, including current signal-to-noise ratio (SNR), detected SNR, bandwidth of serving eNB, bandwidth of target eNB, and remaining energy of a user device, are inputted to the fuzzy logic mechanism to determine whether a handover is required. Four different membership functions are also adapted, namely Z shape, Gaussian, S shaped, and triangular functions, to fuzz the input parameters into defined fuzzy terms. Our simulation results show that the FPEHS can reduce 68.79 % of handover and 92.94 % of ping-pong effect in average. The outcome confirms that the fuzzy logic used for handover decision effectively mitigate the ping-pong effects. This study also demonstrates that low Current-SNR, high bandwidth and high remaining energy are three key parameters for handover decisions, and a wireless communication environment can exploit the fuzzy logic in handling its handover.

The rest of the paper is organized as follows. Section 2 introduces the related works and the preliminaries of this paper. Section 3 presents the FPEHS. The simulation results and discussion are described in Sect. 4. Section 5 concludes the paper and outlines our future studies.

2 Preliminaries

2.1 Related works

The fuzzy sets have been investigated over 45 years (Zadeh 1965). The fuzzy theory has been popularly applied to various aspects, including finance (Bernardo et al. 2013), human emotion detected (Leu et al. 2014), proportional integral derivative (PID) controller (Kim and Oh 2000), cryptography (Wang et al. 2012; Wu et al. 2013), and biometrics (Srivastava et al. 2014). In a mobile communication environment, an efficient handover algorithm is often required to support seamless communication services. Many studies (Ghanem et al. 2012; Monil et al. 2013; Barolli et al. 2008; Yang and Rong 2011; Feng et al. 2013; Xia et al. 2007; Sharma and Khola 2012) adopted fuzzy logic to make handover decision due to its fast processing speed.

Ghanem et al. (2012) presented a handover algorithm which keeps the old path between the serving eNB and Mobility Management Entity (MME)/Serving Gateway (S-GW) during the Ping-Pong effect, and delays the handover procedure. In this algorithm, a timer was utilized to help the decision of whether the ongoing handover is a normal one or a ping-pong effect. The timer starts to work when the signal strength of the target eNB is higher than that of the serving eNB. Owing to the use of the timer, handover processing delay is often long. Monil et al. (2013) introduced a fuzzy logic based handover algorithm to avoid ping-pong effects. Its fuzzy inference system determines the best candidate base station (BS) based on the measurements of relative speed and direction, traffic load, signal strength and the distance between UE and BS. Barolli et al. (2008), three input parameters were utilized as the fuzzy inputs, including the change of signal strength of the present BS, the signal strength received from the neighbour BS, and the distance between MS and BS. The authors also claimed that this system can avoid Ping-pong effect. However, Ghanem et al. (2012); Monil et al. (2013); Barolli et al. (2008) did not address the key parameter in a heterogeneous network, i.e., bandwidth.

Yang and Rong (2011) inputted the received signal strength (RSS) of a MS, the network available bandwidth

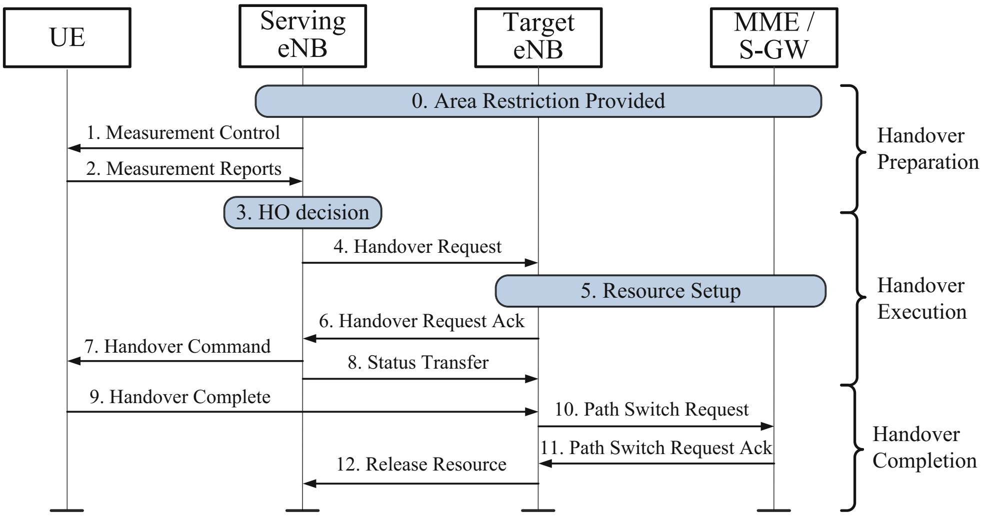

Fig. 1 The handover procedure of the LTE

and the cost of the fuzzy logic controller as the parameters of "the *v*alue of the final *c*omprehensive *p*erformance of the *n*etwork (VCPN)", and made a handover decision according to the VCPN. In this system, making a seamless handover and selecting an appropriate network in time were the key concerns. Feng et al. (2013), a low-complexity fuzzy logic control based vertical handoff decision algorithm was introduced to shorten the decision time. This algorithm, a technique on the basis of a rough set theory, was presented to decrease the number of fuzzy logic decision rules, select core parameters for fuzzy logic controllers and then estimate the value of access network candidacy.

Xia et al. (2007) presented a forward differential prediction algorithm to predict the RSS of neighbour BS. Similar to other studies, three parameters, including current RSS, predicted RSS, and available bandwidth, are utilized to investigate the candidate networks, so that the call dropping rate and unnecessary handover can be possibly avoided. Besides, according to these parameters, in Sharma and Khola (2012), an extra parameter, i.e., user preference, was added as one of the inputs of its fuzzy logic handover decision system. Although the unnecessary handover can be effectively reduced, in Xia et al. (2007) and Sharma and Khola (2012), the algorithm predicting RSS indeed increases the system complexity.

2.2 LTE handover process

In the 3rd Generation Partnership Project (3GPP) standard Roessler and Kottkamp (2013), handover in LTE is specified as "break-before-connect" (also known as break-before-make) or hard handover. Technologies which use hard handovers usually re-establish the connection to the source cell if the connection to the target cell cannot be successfully made. Figure 1 illustrates the procedure of operations and message exchanged among UE, Serving eNB, Target eNB and MME/S-GW.

As shown, the LTE handover procedure has 3 stages, including handover preparation, execution, and completion. In the handover preparation, UE, serving eNB and target eNB prepare the signalling data before the UE connects to the target eNB. At first, the serving eNB configures and triggers the UE to set the parameters for signal strength measurement and choose thresholds for these parameters (step 1). Then, in step 2, the UE sends a measurement report, carrying received signal strength indicator (RSSI) and signal quality, to the serving eNB. After receiving the measurement report, the serving eNB determines whether the UE's handover is required by invoking its handover algorithm (step 3).

In the handover execution stage, the serving eNB issues a HANDOVER REQUEST message to the target eNB (step 4), passing necessary information to the target side for preparing a handover. The target eNB checks its resource availability and, if available, reserves the resources and sends their related information back (step 5). Then, the HANDOVER REQUEST ACKNOWLEDGE message is delivered to the serving eNB to perform the handover (step 6). After receiving the acknowledge message, the serving eNB transmits a handover command to the UE (step 7). UE then detaches itself from the serving cell and synchronizes itself to the target one.

After that, the MME/S-GW switches the path of downlink data to the target side (step 8). For this, the MME/S-GW exchanges massages with target eNB (steps 10 and 11). Upon the reception of the release message sent by target eNB, the serving eNB releases radio and control of related resources (step 12). Subsequently, the target eNB transmits the downlink packet data to UE to complete the handover procedure.

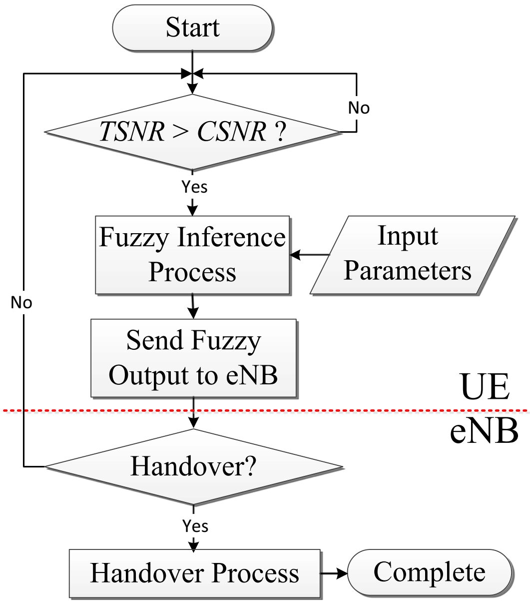

Fig. 2 The handover decision flow of the FPEHS

In the standard LET handover decision process, parameter RSRP is the linear average value of reference signal power across the specified bandwidth (Roessler and Kottkamp 2013). When the system satisfies Eq. (1), the handover procedure will be triggered.

$$\mathrm{RSRT_T} > \mathrm{RSRP_S} + \mathrm{HOM} \tag{1}$$

where $\mathrm{RSRT_T}$ and $\mathrm{RSTR_S}$ represent the UE's signal power received from the target eNB and the serving eNB, respectively, and HOM is the handover margin which is a constant threshold indicating the difference between $\mathrm{RSRT_T}$ and $\mathrm{RSTR_S}$.

3 The FPEHS

3.1 System overview

Figure 2 shows the handover decision flow of the FPEHS, in which the fuzzy inference process is the key component of handover decision. When the UE has achieved its handover triggering condition, i.e., the target SNR (TSNR for short) is larger than current SNR (CSNR for short), the fuzzy inference process will be invoked with five input parameters, including TSNR, CSNR, current bandwidth (CBW), target bandwidth (TBW), and remaining energy (RE) of user's device. The output of the fuzzy process, named Handover Decision (HO), will be sent to the eNB. On receiving the output, the eNB will determine whether handover is required or not.

Figure 3 illustrates the structure of the fuzzy inference process, which consists of four parts, including fuzzification, fuzzy rule base, fuzzy inference engine and defuzzification, with the above mentioned five input parameters, which as an input vector is an extension of a multivalued logic, and one output parameter, which is an approximate value. The fuzzification is the process of transforming crisp values into the grades of a membership function, denoted by T(X)s where X may be CSNR, TSNR, CBW, TBW and RE, i.e., T(CSNR), T(TSNR), T(CBW), T(TBW), and T(RE), respectively. The function in turn associates a grade to a linguistic term. We will describe it in Sect. 3.2. Fuzzy inference engine is a method that interprets the values of the input vector and, based on some set of rules, assigns fuzzy values to its output, i.e., T(HO) where HO may be hold or handover. In the FPEHS, Mamdani's fuzzy inference method is applied. Defuzzification is a process that maps an output fuzzy value to a crisp set. In this study, the output parameter HO is used to determine whether handover is required or not.

3.2 Membership functions

In the FPEHS, as stated above, four membership functions are used, including Triangular, Z-shaped, S-shaped, and Gaussian. Equations (2)–(5) show their mathematical expressions, respectively.

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-c}, & a \le x < b \\ 1, & x = b \\ \frac{c-x}{c-b}, & b < x \le c \\ 0, & x > c \end{cases} \tag{2}$$

$$\mu_{\tilde{A}}(x) = \begin{cases} 1, & x \le \alpha \\ 1 - 2(\frac{x-\alpha}{\gamma-\alpha})^2, & \alpha \le x \le \beta \\ 2(\frac{x-\gamma}{\gamma-\alpha})^2, & \beta \le x \le \gamma \\ 0, & x \ge \gamma \end{cases} \tag{3}$$

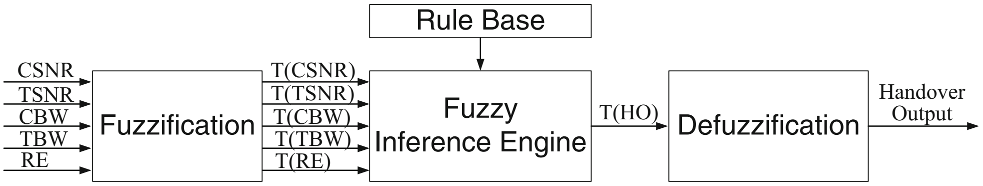

Fig. 3 Fuzzy inference process

Table 1 Parameter settings of fuzzy inputs

Input parameter	Fuzzy term	Membership function	Value of input parameter
Current SNR (CSNR)	Bad	Z-shaped	$\alpha = 10,\ \beta = 17.5,\ \gamma = 25$
	Good	Gaussian	$m = 25,\ \sigma = 5$
	Excellent	S-shaped	$\alpha = 25,\ \beta = 32.5,\ \gamma = 40$
Target SNR (TSNR)	Bad	Z-shaped	$\alpha = 10,\ \beta = 17.5,\ \gamma = 25$
	Good	Gaussian	$m = 25,\ \sigma = 5$
	Excellent	S-shaped	$\alpha = 25,\ \beta = 32.5,\ \gamma = 40$
Current bandwidth (CBW)	Low	Z-shaped	$\alpha = 0,\ \beta = 50,\ \gamma = 100$
	Medium	Gaussian	$m = 220,\ \sigma = 110$
	High	S-shaped	$\alpha = 200,\ \beta = 300,\ \gamma = 400$
Target bandwidth (TBW)	Low	Z-shaped	$\alpha = 0,\ \beta = 50,\ \gamma = 100$
	Medium	Gaussian	$m = 220,\ \sigma = 110$
	High	S-shaped	$\alpha = 200,\ \beta = 300,\ \gamma = 400$
Remaining energy (RE)	Low	Triangular	$a = -5,\ b = 0,\ c = 5$
	Medium	Triangular	$a = 0,\ b = 5,\ c = 10$
	High	Triangular	$a = 5,\ b = 10,\ c = 15$
Handover decision (HO)	Hold	Triangular	$a = -1,\ b = 0,\ c = 1$
	Handover	Triangular	$a = 0,\ b = 1,\ c = 2$

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x \le \alpha \\ 2(\frac{x-\alpha}{\gamma-\alpha})^2, & \alpha \le x \le \beta \\ 1 - 2(\frac{x-\gamma}{\gamma-\alpha})^2, & \beta \le x \le \gamma \\ 1, & x \ge \gamma \end{cases} \tag{4}$$

$$\mu_{\tilde{A}}(x) = e^{(-\frac{(x-m)^2}{\sigma^2})} \tag{5}$$

In these equations, $\mu_{\tilde{A}}(x)$ is the output of a membership function. In Eq. (2), the parameter b denotes a typical value of the fuzzy set, while a and c are the values of the lower and upper bounds of the input value, respectively. In Eqs. (3) and (4), β defined as $(\gamma + \alpha)/2$ is the crossover point of S-function. It is a typical value of the fuzzy set, whereas α and γ are the values of the lower and upper bounds of the input value, respectively. In Eq. (5), the modal value m represents the typical element of $\mu_{\tilde{A}}(x)$, and σ denotes a spread of $\mu_{\tilde{A}}(x)$. Higher values of σ correspond to larger spreads of the fuzzy sets.

The four membership functions are individually given the five mentioned input parameters. Six fuzzy sets are defined as follows.

1. Current SNR: T(CSNR) = {Bad, Good, Excellent}
2. Detected SNR: T(TSNR) = {Bad, Good, Excellent}
3. Current bandwidth: T(CBW) = {Low, Medium, High}
4. Detected bandwidth: T(TBW) = {Low, Medium, High}
5. Remaining energy: T(RE) = {Low, Medium, High}
6. Handover decision: T(HO) = {Hold, Handover}

Each set has three fuzzy terms either bad, good and excellent (called bad set) or low, medium, and high (named low set), except the handover decision set, the value of which can only be hold or handover.

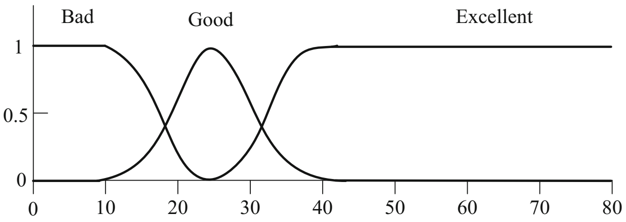

Fig. 4 Input parameter *CSNR*/*TSNR* of three membership functions (Bad: Z-shaped; Good: Gaussian; Excellent: S-shaped)

The parameter settings of the five inputs are listed in Table 1, in which the Z-shaped membership function is given bad or low term of CSNR/TSNR/CBW/TBW, while Gaussian member function is given good or medium fuzzy term, and S-Shaped is only inputted excellent or high. Triangular membership function is applied to RE and HO. The values assigned to the input parameters of a membership function in the following simulation are listed in the fourth column of Table 1.

The five input parameters of a membership function in the FPEHS are illustrated in Figs. 4, 5, 6 and 7. For the former three, each figure employs three member functions. For example, in Fig. 4, bad, good and excellent terms as listed in Table 1, respectively, belong to Z-shaped, Gaussian and S-shaped member functions. The other two figures are configured in the similar method. But in Figs. 6 and 7, only Triangular member function is adopted.

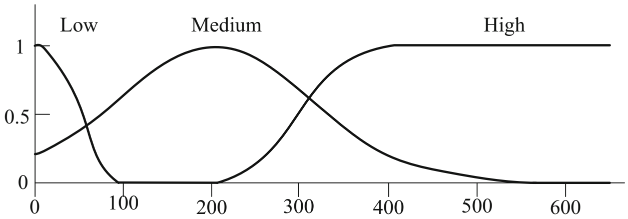

Fig. 5 Input parameter *CBW/TBW* of three membership functions (Low: Z-shaped; Medium: Gaussian; High: S-shaped)

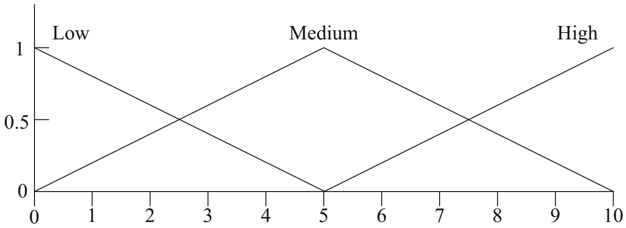

Fig. 6 Input parameter RE of Triangular membership function (Low, Medium, High: Triangular)

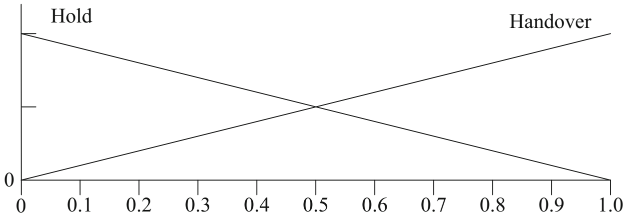

Fig. 7 Output parameter HO of Triangular membership function (Hold, Handover: Triangular)

3.3 Fuzzy rules base and inference engine

The employed fuzzy Rules Base comprises all possible relationships among the five input parameters and one output parameter in IF-THEN format. Since each input parameter has 3 fuzzy terms, a total number of 243 (=3^5) rules are then generated for the five input parameters. Table 2 shows 68 handover rules, each of which is a combination making $T(\mathrm{HO}) = handover$.

In the fuzzy inference engine, the Mamdani model converts aggregated fuzzified data, expressed as

$$\mu_{\tilde{A}_{\mathrm{HO}}} = \max_k[\min[\mu_{\tilde{A}_{\mathrm{CS}}}(\mathrm{CSNR}), \mu_{\tilde{A}_{\mathrm{DS}}}(\mathrm{TSNR}), \mu_{\tilde{A}_{\mathrm{CB}}}(\mathrm{CBW}), \mu_{\tilde{A}_{\mathrm{DB}}}(\mathrm{TBW}), \mu_{\tilde{A}_{\mathrm{RE}}}(\mathrm{RE})]], \quad \text{for } k = 243.$$

into normalized scores. In this study, the Centroid method (Takagi and Sugeno 1985), also known as the center of gravity, is adapted as the defuzzification function which can be expressed as

$$\mathrm{HO}^* = \frac{\int x\mu_{\tilde{A}_{\mathrm{HO}}}(x)\mathrm{d}x}{\int \mu_{\tilde{A}_{\mathrm{HO}}}(x)\mathrm{d}x}$$

where HO* is the score of the handover decision.

4 Simulation results and discussion

To verify the feasibility and correctness of the proposed method, the MATLAB tool is utilized to simulate the FPEHS. Three eNBs and one UE are used given two different moving methods, random walk and straight walk (see Fig. 8). The moving paths and directions are generated by MATLAB, and each moving method is simulated 100 times. The simulation environment and parameter settings are listed in Table 3.

4.1 Simulation result

Table 4 shows the simulation results of the standard LTE, Ghanem's method (Ghanem et al. 2012) and the FPEHS. The column named *No. of Handover* indicates the average UE handover times during the simulation, and the column denoted by *No. of Ping-Pong* is the average ping-pong frequency. As listed in Table 4, the proposed FPEHS can reduce 68.79 % of unnecessary handover and 92.94 % of ping-pong effects compared to those of the standard LTE. Besides, when compared with Ghanem's method, the FPEHS also has better handover results.

4.2 Discussion

In the following, we show how input parameters affect the ping-pong effect, and present the handover results, each of which is obtained by given two independent input parameters. Figure 9 shows the relationship among HO, CSNR and TSNR. The handover occurs (HO value > 0.5) on bad CSNR and good/excellent TSNR, indicating that CSNR is a dominant factor of the handover process, i.e., when CSNR is bad, the UE would attempt to hand over to another eNB. To reduce ping-pong effect, the handover occurs only when CSNR is poor and cannot continue supporting the communication between UE and serving eNB. Of course, currently UE is located at the boundary of serving eNB. At that time, if the SNR of target eNB is strong enough to provide good communication quality, the UE will hand over to the target eNB. However, if both CSNR and TSNR are bad, the proposed fuzzy decision system will keep the connection between UE and serving eNB.

The relationship among HO, and CBW and TBW is shown in Fig. 10, in which the handover also occurs on low CBW with medium/high TBW. Medium and high CBWs do not trigger the handover process. Similar to that in Fig. 9, only when CBW cannot provide enough bandwidth for UE, but

Table 2 68 input-parameter combinations that make the output parameter HO to be *handover*

CSNR	TSNR	CBW	TBW	RE	CSNR	TSNR	CBW	TBW	RE
Bad	Excellent	Low	Low	Low	Bad	Excellent	Medium	High	Medium
Bad	Good	Bad	Medium	Low	Good	Excellent	Medium	High	Medium
Bad	Excellent	Bad	Medium	Low	Bad	Excellent	High	High	Medium
Bad	Good	Medium	Medium	Low	Bad	Good	Low	Low	High
Bad	Excellent	Medium	Medium	Low	Bad	Excellent	Low	Low	High
Bad	Excellent	High	Medium	Low	Bad	Good	Medium	Low	High
Bad	Bad	Low	High	Low	Bad	Excellent	Medium	Low	High
Bad	Good	Low	High	Low	Bad	Bad	Low	Medium	High
Bad	Excellent	Low	High	Low	Good	Bad	Low	Medium	High
Good	Excellent	Low	High	Low	Bad	Good	Low	Medium	High
Bad	Good	Medium	High	Low	Good	Good	Low	Medium	High
Good	Excellent	Medium	High	Low	Excellent	Good	Low	Medium	High
Bad	Good	High	High	Low	Bad	Excellent	Low	Medium	High
Bad	Excellent	High	High	Low	Good	Excellent	Low	Medium	High
Bad	Excellent	Low	Low	Medium	Bad	Bad	Medium	Medium	High
Bad	Bad	Medium	Low	Medium	Bad	Good	Medium	Medium	High
Bad	Excellent	Medium	Low	Medium	Bad	Excellent	Medium	Medium	High
Bad	Excellent	High	Low	Medium	Bad	Excellent	High	Medium	High
Bad	Bad	Low	Medium	Medium	Bad	Bad	Low	High	High
Bad	Good	Low	Medium	Medium	Bad	Good	Low	High	High
Bad	Excellent	Low	Medium	Medium	Good	Good	Low	High	High
Good	Excellent	Low	Medium	Medium	Excellent	Good	Low	High	High
Bad	Good	Medium	Medium	Medium	Bad	Excellent	Low	High	High
Bad	Excellent	Medium	Medium	Medium	Good	Excellent	Low	High	High
Good	Excellent	Medium	Medium	Medium	Excellent	Excellent	Low	High	High
Bad	Excellent	High	Medium	Medium	Bad	Bad	Medium	High	High
Bad	Bad	Low	High	Medium	Bad	Good	Medium	High	High
Bad	Good	Low	High	Medium	Good	Good	Medium	High	High
Good	Good	Low	High	Medium	Bad	Excellent	Medium	High	High
Bad	Excellent	Low	High	Medium	Good	Excellent	Medium	High	High
Good	Excellent	Low	High	Medium	Excellent	Excellent	Medium	High	High
Excellent	Excellent	Low	High	Medium	Bad	Good	High	High	High
Bad	Bad	Medium	High	Medium	Good	Good	High	High	High
Bad	Good	Medium	High	Medium	Bad	Excellent	High	High	High

TBW has sufficient bandwidth, handover will occur, meaning that the FPEHS reduces handover as much as it can to lower ping-pong effect. When both CBW and TBW are low, the FPEHS keeps UE staying at serving eNB.

From Figs. 9 and 10, it is clear that, in the FPEHS, CSNR and CBW play important roles for handover. The relationship among HO, CSNR and CBW is shown in Fig. 11, in which handover occurs on bad CSNR and low CBW. However, handover does not occur on excellent CSNR, even CBW is low. We can then conclude that the importance of CSNR in fuzzy handover decision is much higher than that of CBW.

The relationship among HO, CSNR and RE is illustrated in Fig. 12, in which no matter whether RE is high or low, the handover occurs when CSNR is bad, indicating that, for ping-pong effect, CSNR is more important than RE. When CSNR is good or excellent, the UE does not need to hand over to target eNB, thus eliminating unnecessary handover. Generally, when CSNR is better than TSNR, high RE may provide strong radio signal between UE and target eNB, and it may cause unnecessary handover, thus inducing ping-pong effect. But the FPEHS can avoid this phenomenon.

Figure 13 shows the relationship among HO, CBW and RE. The handover does not occur when CBW is high. Compared with RE, CBW is a key parameter for fuzzy handover decision process. Once serving eNB cannot offer sufficient bandwidth for UE, and the remaining energy of UE is good

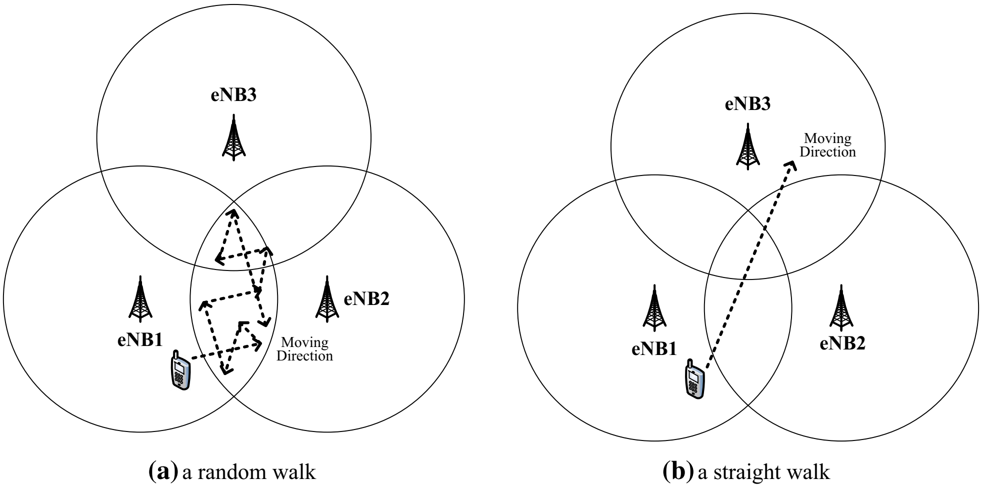

Fig. 8 Examples of a random walk and a straight walk inside the serving range of three neighbor eNBs

Table 3 Simulation environment and parameter settings of our simulation

Parameter	Value
Noise type	White noise
Channel bandwidth	20 MHz
Distance between eNBs	0.75 km
Modulation and coding schemes	64-QAM; 6 bits
eNB serving range	1 km
eNB signal strength	46 dbm
UE moving method	Random/straight
HO threshold	0.5
Simulation times	100 times

Table 4 Simulation results of the standard LTE and FPEHS

Moving method	Methods	No. of handover	No. of ping-pong
Random	Standard LTE	13.86	3.96
	Ghanem et al. (2012)	1.18	0.18
	FPEHS	0.74	0.05
Straight	Standard LTE	5.03	1.83
	Ghanem et al. (2012)	4.21	1.85
	FPEHS	2.87	0.24
Average reduction percentage		68.79 %	92.94 %

enough to provide good communication quality between UE and target eNB, handover occurs. However, when CBW and RE are both low, the handover does not occur, thus again reducing the ping-pong effect.

Figure 14 shows the relationship among HO, TSNR and RE. Figure 15 illustrates the relationship among HO, TBW, and RE. Both indicate that a higher HO appears on good/excellent TSNR and high RE, and medium/high TBW and high RE. On the other hand, the handover does not occur on low TSNR and TBW, even if the UE has high RE. These two figures indicate that RE should be considered together with TSNR or TBW when applying them to the fuzzy decision system.

From Figs. 9, 10, 11, 12, 13, 14 and 15, low HO often occurs on bad TSNR, low TBW, and low/medium RE. It is interesting to note that the ping-pong effect often appears in the overlapping area of the eNBs' boundary. In such an area, CSNR and TSNR might be bad to cause frequent handover. In the FPEHS, the handover decision is made depending on five input parameters, not just only on CSNR or TSNR, and the output value must be greater than 0.5. Namely, the UE keeps connecting to the serving eNB when the output value of the fuzzy logic is smaller than the threshold, thus significantly reducing the ping-pong effect and leading to the conclusion that, in the FPEHS, bad CSNR, high CBW and high RE may cause handover. The outcome confirms that the fuzzy-logic based handover decision system provides an effective ping-pong effect reduction.

5 Conclusion and future studies

To reduce the ping-pong effect, in this paper, the FPEHS is proposed by using the fuzzy logic based decision policy on the LTE communication environment. In average, about 68.79 % of unnecessary handover and 92.94 % of ping-pong effects are reduced. Five input parameters, including CSNR, TSNR, CBW, TBW, and RE, are utilized for the fuzzy-logic inputs. Z-shape, Gaussian, S-shape, and triangular membership functions are also applied to the FPEHS. The simulation results confirm that the fuzzy-logic handover decision can effectively reduce ping-pong effect. In addition, low CSNR, high CBW and high RE are three key input values of the

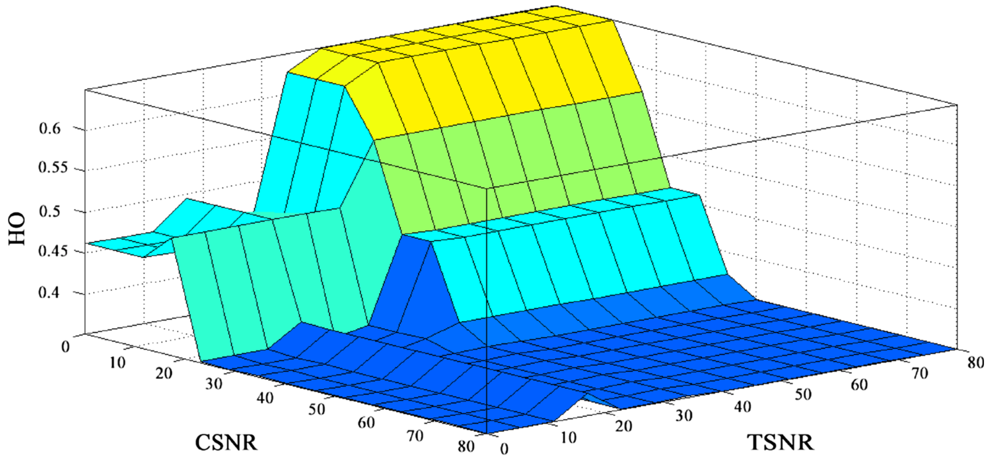

Fig. 9 The relationship among HO, CSNR and TSNR

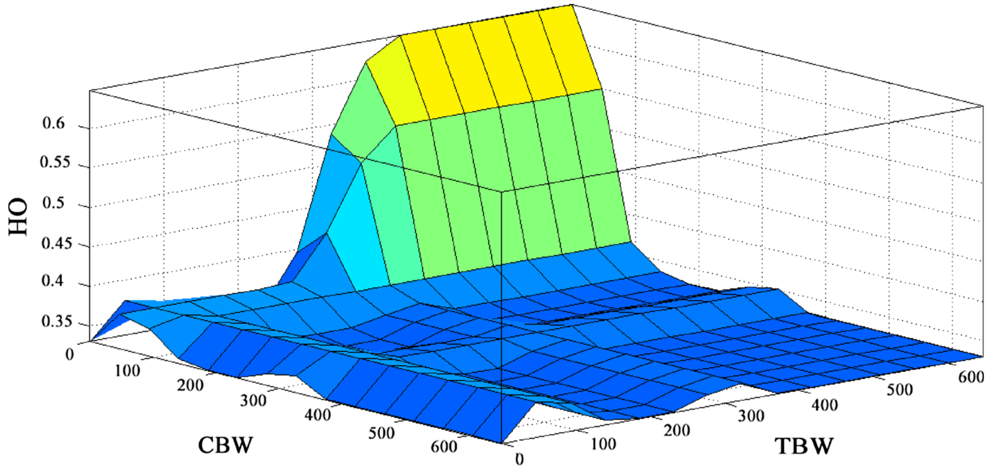

Fig. 10 The relationship among HO, CBW and TBW

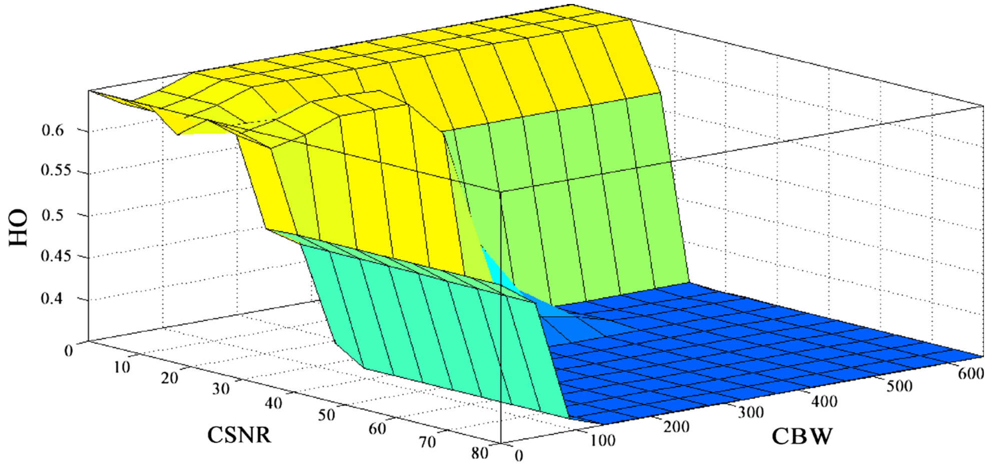

Fig. 11 The relationship among HO, CSNR and CBW

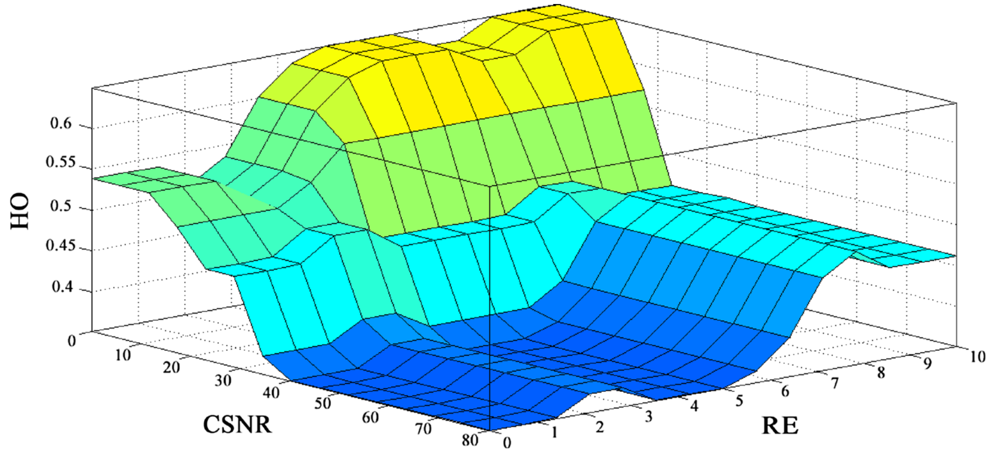

Fig. 12 The relationship among HO, CSNR and RE

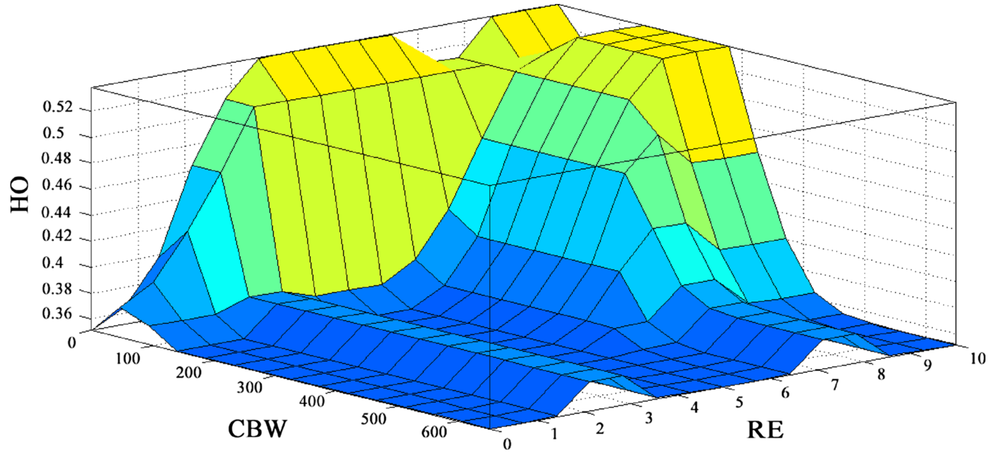

Fig. 13 The relationship among HO, CBW and RE

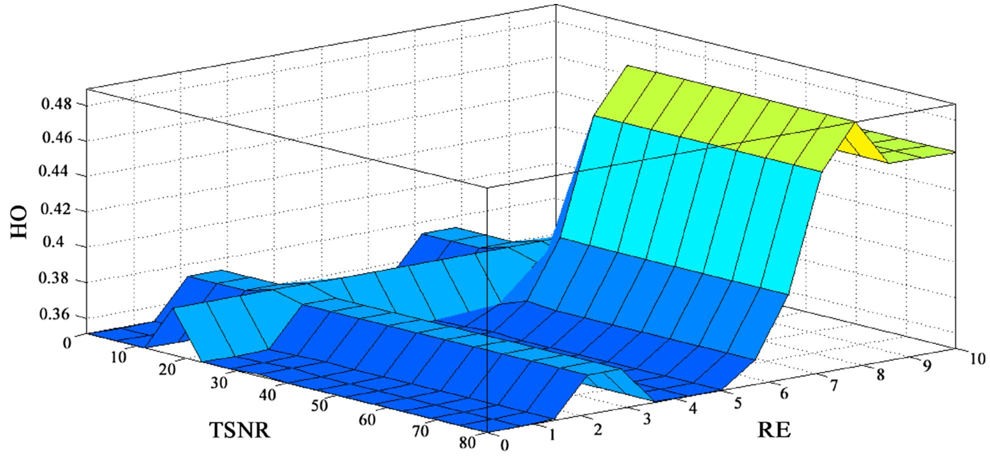

Fig. 14 The relationship among HO, TSNR and RE

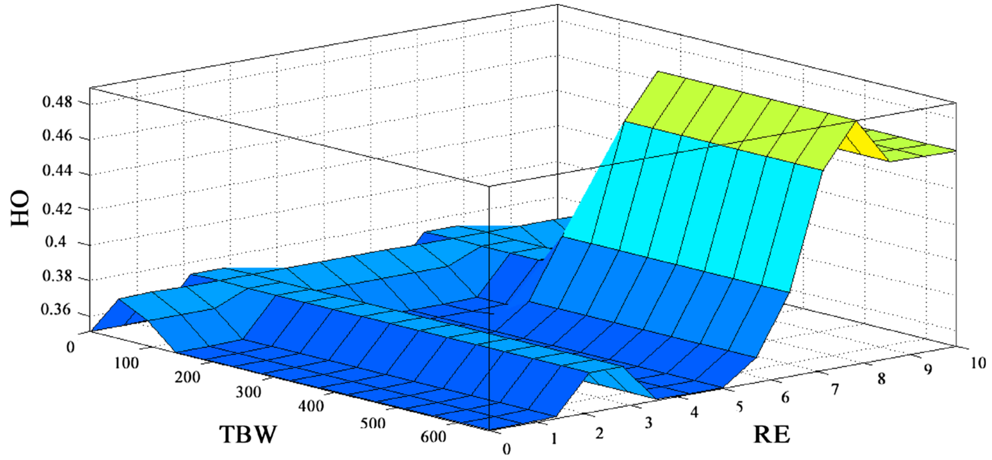

Fig. 15 The relationship among HO, TBW and RE

FPEHS due to their positively related to HO. This study also indicates that we can exploit fuzzy logic to avoid unnecessary handover in a wireless communication environment.

In the FPEHS, although the ping-pong effect has been greatly suppressed, how to identify other effective parameters that can effectively substitute for some or all of the employed five input parameters to further improve the performance of the FPEHS is an important research issue. In addition, the fuzzy logic should also be used for the vertical handover process. We would also like to derive the reliability model of FPHES so that users can predict its reliability before using it. These constitute our future studies.

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