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DOCTORAL THESIS STATEMENT

Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Telecommunication Engineering

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OPTIMISATION OF HANDOFF PROCESS IN WIRELESS NETWORK WITH USE OF FUZZY LOGIC

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Those interested may get acquainted with the doctoral thesis concerned at the Dean Office of the Faculty of Electrical Engineering of the CTU in Prague, at the Department for Science and Research, Technická 2, Praha 6.

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1. CURRENT SITUATION OF THE STUDIED PROBLEM

Mobility is the most important feature of a wireless cellular communication system. In addition to that, the number of portable devices that need access to the Internet is exponentially increasing. Usually, continuous service is achieved by supporting handover from one cell to another. Handover is the process of changing the channel (frequency, time slot, spreading code, or combination of them) associated with the current connection while a call is in progress. It is often initiated either by crossing a cell boundary or by deterioration in quality of the signal in the current channel. Handover is divided into two broad categories − hard and soft. They are also characterized by „break before make" and „make before break". In hard handover, current resources are released before new resources are used; in soft handover, both exist and new resources are used during the handover process [1]. In conventional handoff the mobile device monitors received signal power levels, and exchanges this data with base station (BS). Current BS assesses the data, makes decision about handoff execution and chooses target BS.

In today networks, to perform evaluation of handover a variety of initiation criteria, described in Chapter 1.3 of doctoral thesis, are taken into consideration. Based on mobile station (MS) movement from one BS (BS_1) to a further one (BS_2), it can be visualise in simplified way that the average signal strength of BS_1 decreases while the distance between MS and BS_1 increases. In the same way, the average signal strength of BS_2 increases as the MS is getting closer to BS_2 [2].

Relative Signal Strength

This method is based on relative signal strength measurements, meaning that the BS with the strongest signal is selected all times. It has been noticed that RSS can generate too many avoidable handovers, for example, when the signal of the current BS is still at acceptable level [3].

Relative Signal Strength with Threshold

This method specifies additional criterion, a threshold. The MS is measuring the signal strength, however the handover occurs only when the current signal decreases below the fixed threshold and the new signal is stronger than the previous. The effect of the threshold depends on its relative value as compared to the signal strengths of the two BSs at the point at which they are equal. By using this idea a threat of overlapping cell coverage areas exists. That is why a threshold is not used alone in practice, due to its efficiency depends on prior knowledge of the crossover signal strength between the present and adjoining BSs [4].

Relative Signal Strength with Hysteresis

The main principle of this method is to allow triggering of handover mechanism only if the target BS signal is strong enough in comparison to the one being in use. The process of checking signal eligibility for handover is based on a hysteresis margin. The method benefits from the ping pong effect being completely eliminated [5].

Relative Signal Strength with Hysteresis and Threshold

As the subject indicates, this method takes into consideration both the hysteresis and the threshold. Consequently, the handover occurs under following conditions: if the current signal decreases below the threshold specified, and if the target BS emits signal stronger than the one defined by hysteresis margin h. The scheme benefits from the fact that the handover is not performed as long as the signal from the serving BS is sufficiently strong. Moreover, the ping-pong effect is eliminated as well [6].

2. AIMS OF THE DOCTORAL THESIS

1. An overview of the handover process stages and specifications of particular handover methods for present wireless networks.
2. Processing of fuzzy logic principles and review of navigation systems for precise handover process optimisation in wireless networks.
3. Derivation of new multi parameters mechanism for handover decision-making process.
4. Proposal of the real implementation of proposed handoff mechanism in wireless network.

3. WORKING METHODS

As a working method principles of fuzzy logic were chosen. Fuzzy logic allows to lower complexity by allowing the use of imperfect information in sensible way. It can be implemented in hardware, software, or a combination of both. In other words, fuzzy logic approach to problems' control mimics how a person would make decisions, only much faster.

The first step of the fuzzy logic method is to transform the input numerical value to names of member function and values of memberships in the function. Input parameters are fuzzified with use of pre-defined input membership functions.

Second step is to create rule matrix that describes fuzzy sets and fuzzy operators in form of conditional statements: if x is A then y is Z. Handoff fuzzy decision will depend on a rule matrix created based on the known sensitivity of input values.

Third steps should cover inference mechanism that allows mapping given input to an output using fuzzy logic. It uses all pieces described above: membership functions, logical operations and if-then rules.

At the end defuzzification mechanism is applied to find one single crisp value that summarises the fuzzy set [7].

More comprehensive description of fuzzy logic can be found in Chapter 4.1 of doctoral thesis.

4. RESULTS

The main idea of presented handoff scheme is based on the fuzzy logic. The schemes consider not only distance from the target base station, but also the bandwidth usage (data transmission rate) and mobile station velocity. Here, fuzzy logic is used to reach a decision about the target BS to be chosen by handoff controller, such that the handoff is performed as fast as possible with reasonable quality of service levels. It will allow to anticipate or to delay the handoff taking real situation into account based on specified variables.

Case of study

Fuzzy logic processing described below is based on example cell environment (shown in Figure 1) consisting of 7 hexagon cells with 20 km radius. A base station is placed in the middle of each cell. The maximum velocity of MS is 50 m/s and available data rate amounts to 200 Mbps. By changing parameters maximum values, this model can be applied to almost all present wireless networks. Borders of each cell are overlapping to allow soft handover execution. MS is connected to BS_1 and monitors signal from BS_2, BS_3, BS_4 and BS_5.

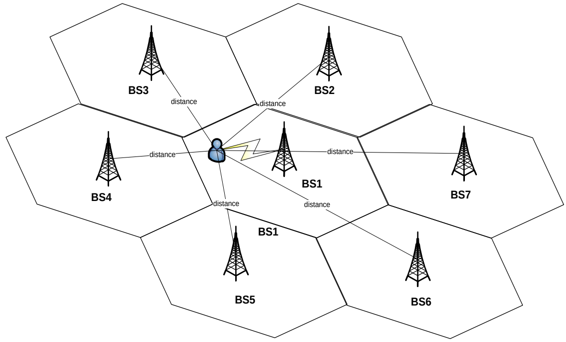

Figure 1. Example environment

In Table 1 a specific situation is presented, where distance from each adjacent BS is known along with bandwidth occupancy in given cell. Each cell represents different network conditions – usage of bandwidth. Assumption is made that the mobile station moves with 40 m/s velocity. The BS_7 and BS_6 are not taken into consideration as the distance to MS is too big.

Table 1. User position and network conditions

	BS_2	BS_3	BS_4	BS_5
Distance	30 km	21 km	19 km	28 km
Bandwidth usage	120 Mbps	100 Mbps	180 Mbps	80 Mbps

Handoff Rule Matrix

Below Table 2 is an example of rules for possible input combination. All rules can be found in Chapter 5.4 of doctoral thesis. For example, if a MS is close to the target BS and the target BS has medium usage of bandwidth and it moves with high speed then the HFO is YES.

Table 2. Example of rules for fuzzy handover

Rule No.	Distance	MS Velocity	Used bandwidth	HFO output
1	Close	High	Medium	Yes
2	Close	High	Low	Yes
….				

Handoff Fuzzification Mechanism

For simulation purposes sinusoidal membership functions were chosen. Figure 2 below is an example of input membership function for distance from target base station. Similar membership functions were created for MS velocity and bandwidth usage and can be found in Chapter 5.5 of doctoral thesis.

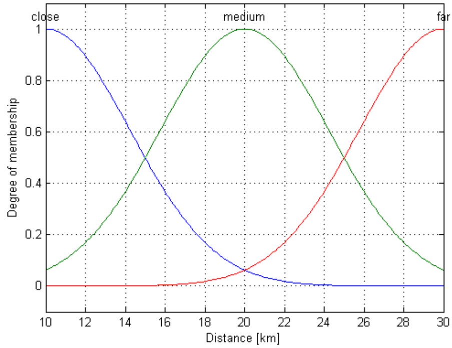

Figure 2. Input membership function of distance from a BS

Table 3 shows values that can be read from membership function graphs for analysed example:

Table 3. Analysed example for BS_4

Input	(Function Name, Degree)	(Function Name, Degree)	(Function Name, Degree)
Distance From BS_3 = 19	(C, 0.11)	(M, 0.97)	(F, 0.03)
MS velocity = 40		(A, 0.19)	(H, 0.48)
Used bandwidth = 180		(MB, 0.06)	(HB, 0.83)

Handoff Fuzzy Output Calculation

The simulation is based on Sugeno reasoning method. Firing strength α_i of the AND rules is calculated as minimum value of all input values for given rule. In Table 4 α_i values (firing level) for each rule of analysed example are calculated.

Table 4. Firing strength of rules

Rule No.	Rule description	HFO output	Firing strength of rule
1	C, H, MB	Yes	min(0.11;0.48;0.06) = 0.06
3	C, A, MB	Yes	min(0.11;0.19;0.06) = 0.06
5	M, H, MB	Yes	min(0.97;0.48;0.06) = 0.06
10	M, H, HB	Be ready	min(0.97;0.48;0.83) = 0.48
11	C, A, HB	Be ready	min(0.11;0.19;0.83) = 0.11
12	C, H, HB	Be ready	min(0.11;0.48;0.83) = 0.11
13	M, A, HB	Be ready	min(0.97;0.19;0.83) = 0.19
14	M, A, MB	Be ready	min(0.97;0.19;0.06) = 0.06
19	F, H, HB	Wait	min(0.03;0.48;0.83) = 0.03
20	F, H, MB	Wait	min(0.03;0.48;0.06) = 0.03
22	F, A, HB	No	min(0.03;0.19;0.83) = 0.03
23	F, A, MB	No	min(0.03;0.19;0.06) = 0.03

Chosen situation provided value only for twelve rules. For the rest of curves read out values equals 0.

Consequence of Sugeno method is sought after defuzzified crisped. For needs of a given analyse it was decided that singleton output function are completely sufficient, as it will simplify mathematical computation. Chosen constant values *z* were assigned to individual rule outputs: Yes = 1, Be ready = 0,6667, Wait = 0,3333 and No = 0.

These values should correspond to different physical situation. With high value assigned to specific output, there is a bigger probability that the handoff would be recommended even if the rule output value is N. Based on the equation the crisp control action is calculated as

$$HFO = z_0 = \frac{\sum_{i=1}^{n} \alpha_i \cdot z_i}{\sum_{i=1}^{n} \alpha_i} =$$

$$= \frac{(0.06 \cdot 1) + (0.06 \cdot 1) + (0.06 \cdot 1) + (0.48 \cdot 0.6667) + (0.11 \cdot 0.6667) + (0.11 \cdot 0.6667)}{0.06 + 0.06 + 0.06 + 0.48 + 0.11 + 0.11 + 0.19 + 0.06 + 0.03 + 0.03 + 0.03 + 0.03} +$$

$$+ \frac{(0.19 \cdot 0.6667) + (0.06 \cdot 0{,}6667) + (0.03 \cdot 0{,}333) + (0.03 \cdot 0.3333)}{0.06 + 0.06 + 0.06 + 0.48 + 0.11 + 0.11 + 0.19 + 0.06 + 0.03 + 0.03 + 0.03 + 0.03} = 0{,}67$$

Chosen method assigns values to HFO ranging from 0 to 1, where the following applies: higher value, stronger recommendation for handoff.

Analyse of Fuzzy Handover Mechanism

For each probable target base station, the crisp value of fuzzy logic decision is computed. In result, the BS with highest value of decision is recommended as a target BS. Simulations results are presented in Table 5.

Table 5. HFO results for adjacent BSs

	$\mathbf{BS_2}$	$\mathbf{BS_3}$	$\mathbf{BS_4}$	$\mathbf{BS_5}$
Sugeno	0.249	**0.808**	0.687	0.317

Calculation results for HFO recommendation show that for chosen scenario Sugeno method points BS_3 as the best target base station in given moment. Figures below present simulation results. Graphs are three dimensional, so they present dependency of handover recommendation for two parameters on axis X and Z with third parameter being a constant.

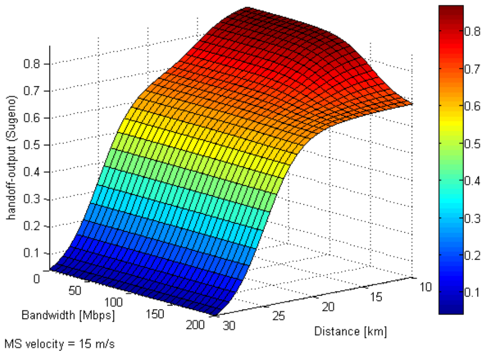

Figure 3. Handover dependence on distance and bandwidth

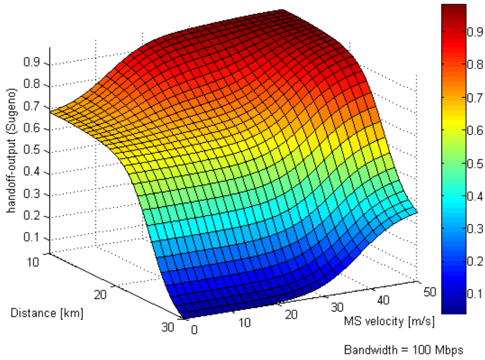

Figure 4. Handover dependence on distance and MS velocity

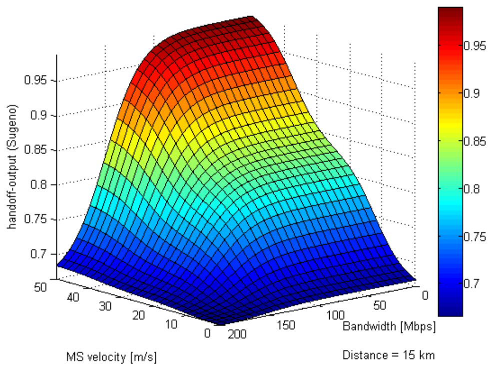

Figure 5. Handover dependence on MS velocity and bandwidth

These graphs show how handoff factor increases as distance of MS from target BS decreases. It is also clear that if MS velocity increases the handoff factor also increases accordingly.

In doctoral thesis Mamdani inference method is also used for simulation purposes.

Comparison of Multiple Parameters Model with Single Parameter Model

To show the advantage of multiple parameters deciding method, in below Table 6 results from multiple parameters fuzzy system are compared with results of calculation covering only one input data: distance from target

BS. Membership function for distance from target BS is the same as for the multiple parameters model, but the rules have change. If MS is close to target BS, the handover should be done. If it is in medium distance, it should wait and if it is far away it should not take any action.

Table 6. Comparison of single input model and multiple input model

	BS_2	**BS_3**	**BS_4**	**BS_5**
Sugeno	0.249	**0.808**	0.687	0.317
Single input Sugeno	0.0294	0.468	**0.532**	0.0797

As it can be read from Table 6, according to single input method, the best target BS is BS_4, as MS is closest to this BS.

Figure 6 shows how handover recommendation is influenced only by the distance from the target BS.

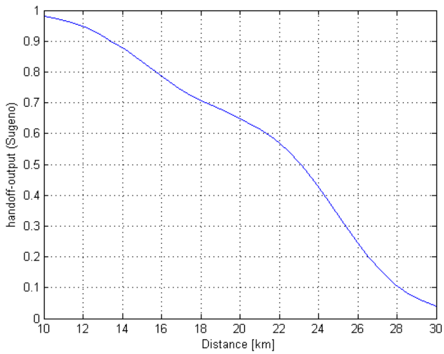

Figure 6. Handover dependence on distance

Today's applied handover algorithms (Chapter 1) are based only on one input value, such as RSS, SIR or distance, which does not provide proper information for handover decision making. If, like in presented analysed example (Table 1), handover initiation would be made based only on distance from target BS, the unquestionable target BS would be BS_4, as the MS is closest to it (Table 6). Nevertheless, it is not marked as the best according to multiple parameters fuzzy logic system because of its bandwidth high load. The best would be BS_3 as it offers better conditions to the MS. Naturally, for decision making and handover initiation is it possible to use more input parameters, than just the three calculated in the modelled example.

Real Implementation of Proposed Handoff Mechanism

Optimisation of network traffic will require the acquisition and processing of additional information in the form of so-called intelligent maps. Intelligent map will include specific and required parameters of the current status of wireless network. It will also cover details about current position of MS, the planned destination point and planned route. Along with the location data end user specifies the type of services and specific QoS level of the service. Technical information about the MS broadcast parameters may be incorporated into intelligent maps automatically with use of service communication.

Decision from handoff controller in conjunction with geographical data and other input parameters, will allow to avoid all unnecessary handoff being a result of landform features.

To illustrate this, the situation in Figure 1 will become slightly more complicated and presented in Figure 7. MS is still inside BS_1 cell and for current position handover is not needed. Then solution of demonstrated example can be as follows.

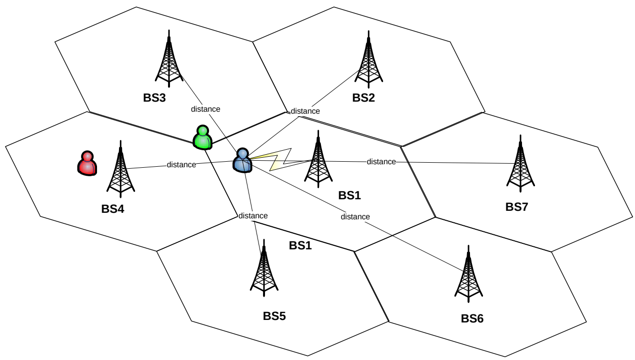

Figure 7. Movement prediction scenario

By knowing the geographical position of MS in given period of time (green or red user in Figure 7), distance from adjacent BS can be determined based on following equation:

$$D = \sqrt{(x_{BS} - x_{MS})^2 + (y_{BS} - y_{MS})^2} \tag{1}$$

The parameters of BS_3 and BS_4 (distance, used bandwidth) will be according to Table 7. It is being assumed that velocity of the MS will not change. Also bandwidth allocation will not change dramatically, so it does not have to be predicted.

Further in this scenario, in future MS will move closer to BS_3 and BS_4 and position itself on the boundary of two cells (green user). It means that the distance from each considered BS is equal and additional factors have to be evaluated to reach the decision about handover execution. Distance from others BSs is too big to be taken into consideration.

Table 7. HFO decision for first predicted position (green)

	BS_3	BS_4
Distance	20 km	20 km
Bandwidth used	100 Mbps	170 Mbps
Velocity	40 m/s	40 m/s
Fuzzy handover	**0,674**	0,517

Table 7 shows that due to additional parameters evaluation (bandwidth allocation), the better target base station is BS_3, as it can offer higher QoS for the user than BS_4.

Going further and predicting position of MS in second point of time. User will move deeper into BS_4 cell.

Table 8. HFO decision for second predicted position (red)

	BS_3	BS_4
Distance	30 km	10 km
Bandwidth used	100 Mbps	170 Mbps
HFO	0,279	**0,745**

Table 8 shows that for second position undeniably much better candidate for handover is BS_4, even if the bandwidth utilisation is much higher than in BS_3. If user moves in predicted direction, eventually he will not have a choice and will have to switch to BS_4. In this way, handover recommended for the first predicted position to BS_3 is not needed and can be avoided.

It can be concluded that fuzzy logic controller output could be complement with additional optimising mechanisms, such us movement prediction, that should allow to improve handover process by avoiding unnecessary handovers. Intelligent maps and prediction of MS movement in wireless network will allow to accurately specify each BS, which MS will connect to during the entire trip. If needed, it could be possible to pass to MS parameters of interest describing predicted target BS. MS could be informed in advance about transmission conditions in specific cell. This approach can be considered as additional service available to users, which requires specific level of provided services. On the network side, it will enable allocation of proper network resources needed for MS.

5. CONCLUSION

The doctoral thesis focuses on the issue of optimising the handover in wireless network. In the introduction it processes known findings and current handover process solutions. With regard to the insufficiency of existing solutions it proposes a new method of multiple parametric deciding on handover process.

New procedure for multiple parameters decision is designed to optimise the traffic in wireless networks. In this statement, the possibility of further development of traffic management network is shown as well, if more parameters handover decision process will be supplemented by additional inputs in the form of complex intelligent maps with prediction of MS motion. All this effort is expected to enable new services with guaranteed transmission rates and quality parameters for end-user devices.

Accomplishment of the Doctoral Thesis Aims

Aim no. 1: An overview of the handover process stages and specifications of particular handover methods for present wireless networks. This objective is addressed in doctoral thesis Chapter 1 and Chapter 2. The first chapter is devoted to general information about the general process of handover in existing wireless networks with cell architecture. First of all, there are the basic methods of decision making and input parameters for decision making commonly used nowadays. Different types of handover strategies and their implementation are explained.

Specifications of particular handover methods for present wireless networks are addressed in doctoral thesis Chapter 2. Chapter 2 describes real implementations of handover process in mobile networks of second and third generation and wireless network WiMAX. Various handover types, their properties and usage can be found described in details.

Aim no. 2: Fuzzy logic principles processing and review of navigation systems for handover process optimisation in wireless networks. This goal is achieved in doctoral thesis Chapter 3. Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra. Chapter 3 of this statement contains a basic overview of the principles of fuzzy logic, which will be used as a mathematical tool to optimise decision-making process of handover.

Aim no. 3: Derivation of a new multiple parameters mechanism for handover decision-making process. This goal is addressed in Chapter 4 of this statement. This chapter presents its own benefits of doctoral thesis. Based on the research work in Chapters 4 of doctoral thesis and the general principles of fuzzy logic, procedure for optimising decision-making process of multiple parameters handover in wireless network was derived. Output design parameters, as well as chosen adequate input parameters are listed in section Case of Study. To illustrate the point, in this chapter, example of wireless network is demonstrated, which is being solved throughout the entire chapter. Section „Handoff rule matrix” contains rules created for fuzzy logic, which combine defined input parameters and assigned output parameters. Section „Handoff fuzzufication mechanism” and „Handoff fuzzy output calculation” describes in detail method of determining individual membership functions and method for calculating the output value for the decision process. Section „Analyse of fuzzy handover mechanism” lists the results of optimisation of multiple parameters design for deciding process of handover. Additionally, comparison of multiple parameters fuzzy system with single parameter fuzzy system is presented.

Aim no. 4: Proposal of the real implementation of proposed handoff mechanism in wireless network. This objective is addressed in Chapter 4 of this statement. The „Real implementation of proposed handoff mechanism” is chapter discusses possible future developments in optimisation of wireless network. It refers to the results derived from multiple parameters optimisation process for deciding. A consideration about the further expansion of inputs for the process of decision-making and method of their processing is presented. The modelling example shows possible complement of multiple parameters deciding HFO mechanism and benefits coming from MS motion prediction along with intelligent map. Movement prediction along with fuzzy logic mechanism allows to avoid unnecessary handovers. It can be also implemented as additional service for the MS user that will permit to assure chosen service parameters. At the end, possible alternatives for decision-making process of HFO are being discussed.

As per the aforementioned, all objectives assigned to this doctoral thesis have been met.

List of literature used in the thesis statement

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List of candidate's works relating to the doctoral thesis

Impact

None.

Reviewed

[1] Kozlowska, E.: **Time Precision of Navigation Systems.** In: Access server [online]. 2007, vol. 5., no. 2007030003, p. 200703000. ISSN 1214-9675. Available at: http://access.feld.cvut.cz/view.php?cisloclanku=2007030003.

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Patents

None.

Web of Science

None.

Others

[4] Kozlowska, E.: **Handoff with Movement Prediction in Mobile WiMAX.** In: Workshop 09 CTU REPORTS [CD-ROM]. Prague: CTU, 2009, p. 88-89. ISBN 978-80-01-04286-1.

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[12] Gosiewski, B. - Kozlowska, E.: **Wireless Mesh Networks - Standards and Challenges.** In: RTT 2007 [CD-ROM]. Žilina: University of Žilina, 2007, p. 109-113. ISBN 978-80-8070-735-4. (50%)

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SUMMARY

Nowadays, it is quite obvious that the popularity and importance of wireless networks will continue to increase. Number of end users grows along with their demands on provided services while maintaining a high level of mobility. Therefore, optimisation of wireless networks is gaining on significance.

In order to ensure end-user switching between different cells, the procedure called handover is implemented in networks with cell architecture. Transferring a call or data transmission represents one of the most serious control procedures in the wireless network. Transferring a call or data transmission represents one of the most serious control procedures in the wireless network. A fundamental task for the smooth transfer of call is its realisation in such a short time, so that the subscriber does not lose the connection, and the whole procedure is not noticeable. Optimisation that leads to the increased switching time is topic of research in a number of current scientific papers. In contrast to what has been mentioned above, currently problems associated with decision-making process of the handover execution/ non-execution are not popular topics of research.

Current methods for determining the handover process can be simply compared to black and white view of the world. When making decision about handover execution in general only one parameter is being considered. Providing new services will require more input variables for the handover process.

For multiple parameters deciding on handover process it seems very appropriate to use the principles of Fuzzy Logic. Fuzzy Logic provides a completely different approach. One can concentrate on solving the problem rather than trying to model the system mathematically, if that is even possible. This almost invariably leads to quicker, cheaper solutions. Once understood, this technology is not difficult to implement and the results are usually quite surprising and more than satisfactory.

Multiple parameters deciding on handover process can be complemented with additional input data. A typical example of such data is the mobile station geographical position, the BS position, landform feature, routes network, railway network, etc. This input data can be combined into a

comprehensive intelligent map. Nowadays, some of this input data, such as highways network, is already commonly available. For other input data it is necessary to create new methods of its obtaining and processing. An important indication is the position of the mobile station, which can be gained using the functionalities of a wireless network. A more appropriate way to precisely determine the mobile station position is using one of the existing GNSS systems. Data localizing the position will be obtained using the navigation modules installed in the mobile station. Processing of this data and its placing in the 3D context of intelligent maps will require derivation of new principles and practices. Based on geographic data and information about the mobile station direction vector, it would be possible to predict mobile station movement and execute proper mechanism to assure demand on quality of service.

Implementation of localisation and prediction functions will lead to optimisation of network traffic at higher management levels. Network traffic management or handover at higher layers is interesting from the perspective of mutual convergence of different technologies of wireless networks. In significant way different types of handover can be unified and thanks to this an implementation of handover between different networks and technology could be achieved. However, it is still on distant development roadmap.

RESUMÉ

Tato práce je zaměřena na optimalizaci více parametrického rozhodování o provedení handoveru (předání spojení) v bezdrátové mobilní síti s využitím matematického aparátu fuzzy logiky a s využitím lokalizace a predikce pozice koncového účastníka. V úvodu práce zpracovává známé poznatky a současná řešení procesu handoveru.

Více parametrické rozhodování umožňuje handoveru vhodnějším způsobem vybrat cílovou buňku bezdrátové mobilní sítě. Běžně používané jedno parametrové algoritmy, které se rozhodují pouze na základě vybraného parametru na radiovém rozhraní, jako je například Received Signal Strength nebo Signal-to-Interference Ratio anebo se rozhodují na základě známé vzdálenosti koncového zařízení od cílové buňky, neumožňují komplexní přístup v řešení konkrétní situace. Navrhovaný mechanismus pro optimalizaci rozhodování ve výběru cílové buňky bere v úvahu nejen vzdálenost, ale i rychlost pohybu koncového zařízení a využití šířky pásma v cílové buňce. Výsledky více parametrického rozhodování jsou v práci diskutovány a porovnávány se stávajícími řešením. V závěru práce je ukázána možnost dalšího vývoje řízení provozu sítě, pokud bude více parametrické rozhodování o handoveru doplněno o další vstupy v podobě Inteligentní mapy s predikcí pozice a pohybu koncového účastníka.

Všechno toto úsilí má umožnit optimalizovanější provoz bezdrátové mobilní sítě a vést tak například i k možnosti poskytovat nové služby s garantovanými přenosovými i kvalitativními parametry pro koncového účastníka.