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On a Reliable Handoff Procedure for Supporting Mobility in Wireless Sensor Networks

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Abstract

Wireless sensor network (WSN) applications such as patients' health monitoring in hospitals, location-aware ambient intelligence, industrial monitoring /maintenance or homeland security require the support of mobile nodes or node groups. In many of these applications, the lack of network connectivity is not admissible or should at least be time bounded, i.e. mobile nodes cannot be disconnected from the rest of the WSN for an undefined period of time. In this context, we aim at reliable and real-time mobility support in WSNs, for which appropriate handoff and re-routing decisions are mandatory. This paper drafts a mechanism and correspondent heuristics for taking reliable handoff decisions in WSNs. Fuzzy logic is used to incorporate the inherent imprecision and uncertainty of the physical quantities at stake.

On a Reliable Handoff Procedure for Supporting Mobility in Wireless Sensor Networks

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Abstract

Wireless sensor network (WSN) applications such as patients' health monitoring in hospitals, location-aware ambient intelligence, industrial monitoring /maintenance or homeland security require the support of mobile nodes or node groups. In many of these applications, the lack of network connectivity is not admissible or should at least be time bounded, i.e. mobile nodes cannot be disconnected from the rest of the WSN for an undefined period of time. In this context, we aim at reliable and real-time mobility support in WSNs, for which appropriate handoff and re-routing decisions are mandatory. This paper[1] *drafts a mechanism and correspondent heuristics for taking reliable handoff decisions in WSNs. Fuzzy logic is used to incorporate the inherent imprecision and uncertainty of the physical quantities at stake.*

1. Introduction

We aim at supporting reliable and real-time communications in Wireless Sensor Networks under nodes' mobility. Reliable and real-time mobility support can be associated to patients' health monitoring in a hospital, process/maintenance personnel in a factory floor, mobile robots or human surveillance in homeland security. This concerns both individual nodes and node groups (e.g. body sensor network) mobility – usually dubbed as "physical mobility".

The problem is that current WSN protocols do not permit to fulfil reliability and real-time requirements under physical mobility. Mobility support in WSNs is in its preliminary steps, since the majority of the current WSN applications assume nodes are static. In this line, most WSN protocols (e.g. ZigBee) just support joining/leaving of nodes, leading to unbounded network inaccessibility times, resulting in unacceptable message delays or losses.

Additionally, radio interference, environmental characteristics and nodes mobility turn radio links unpredictable, leading to message error/losses. This is more acute for low-cost low-power nodes operating in an increasingly crowded 2.4 GHz ISM (Industrial, Scientific, and Medical) band (e.g. WiFi, ZigBee, Bluetooth, cordless phones, microwave ovens or video transmitters).

In this context, we have been addressing the design of an optimal handoff procedure, building upon an accurate estimation of the radio link quality between the mobile node (MN) and the surrounding access points (APs, defined as connectivity points to the rest of the WSN, e.g. routers or cluster-heads) and several other important parameters (e.g. traffic load or energy level at the APs). Handoff refers to the process where a mobile node disconnects from one AP and connects to another AP.

The proposed handoff heuristic (Section 3) is based on Fuzzy Logic to combine all these "uncertain" metrics. Section 2 outlines some handoff models. We conclude the paper in Section 4.

2. Related Works on Handoff Models

The most widely used criteria for evaluating handoff in wireless networks are bit-error rate (BER) and received signal strength (RSS) as indicators for deciding whether to handoff to a new region. However, considering the RSS criterion individually can lead to inappropriate or unnecessary handoff decisions, particularly in WSN scenarios (harsh environmental conditions and strong resource constraints). For this reason, other parameters such as signal to interference-plus-noise ratio (SINR), distance, velocity, direction, transmit power and traffic load have also been considered.

The remainder of this section summarizes some of the most relevant methodologies that have been adopted for designing handoff mechanisms.

Basically, there are two major families of handoff decision. The most common models are the standard techniques, which are used in cellular, wireless mesh, WLAN, and 6LoWPAN networks [1,2,3,4]. These protocols build upon the mobile IPv6 mobility management mechanism. The handoff procedure in mobile IPv6 is initiated by predicting node mobility according to

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RSS information. The use of this technique in wireless sensor networks is not recommended, since nodes are usually deployed in a harsh environments and low cost radio transceivers and antennas are usually used, at least for large scale WSN scenarios, hence the received signal strength is not stable. Therefore, relying on only one (unreliable) metric may lead to a poor handoff decision.

Some adaptive and heuristic models have been proposed to handle the handoff procedure considering several input parameters. The classification of these models is illustrated in figure 1. Before a detailed description of our approach, we briefly present the following five heuristic models that have been adopted for designing handoff mechanisms.

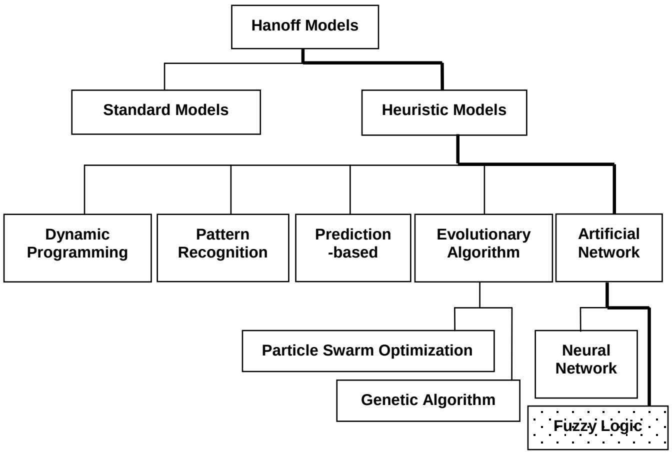

Figure 1. Classes of Heuristic Handoff Models

Dynamic programming allows a systematic approach to optimization. However, it is usually model-dependent and handoff is viewed as a cost optimization problem [5]. RSS samples at the MN are modelled as stochastic processes. The reward is a function of several characteristics such as signal strength, channel fading, shadowing, etc.

In [6], the handoff problem is formulated as a pattern recognition (PR) problem. This technique is based on the idea that the points that are close to each other in a mathematically defined feature space represent the same class of objects or variables. The PR method is an exhaustive method for finding the best possible handoff and is practical only for a canonical (Manhattan) topology but still involves huge computation when applied to generic network topologies.

A prediction based handoff algorithm has been proposed to estimate the future values of handoff criteria, such as RSS. It also shows a trade-off between the number of handoffs and overall signal quality [7].

Some handoff models are based on evolutionary algorithms such as genetic algorithms (GA) and particle swarm optimization (PSO) methods as their optimization technique is used to fine tune the decision parameters. The GA method is an efficient searching technique used for finding the exact or approximate optimization solutions. This method was used in [8] to minimize the sum of weighted distance costs whose complexity is NP-hard.

The other evolutionary algorithm, PSO, is used for handoff decision. It is initialised with a group of random particles (solutions) and looks for an optimum by updating generations. The optimal solutions are called particles which fly through the problem space by following the current optimum particles. In [9], the authors presented a technique for predicting the signal strength value, which aids in providing efficient handoffs in wireless networks and PSO was used to fine tune the weighting function of the handoff decision.

The use of artificial intelligence requires less computational time as compared to the aforementioned searching models, thus seem adequate for time-sensitive applications. Artificial neural networks are one example; they are made up of interconnecting artificial neurons that mimic the properties of biological neurons. These techniques used simplified simulation models (e.g. [10]).

Another example of artificial networks used in handoff is fuzzy logic, which is a multi-valued logic that has been derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. In [11], a handoff decision for heterogeneous networks is identified as a fuzzy multiple attribute decision making problem, and fuzzy logic is applied to deal with the imprecise information.

The use of fuzzy logic is a suitable method for the decision process, because it describes a system intuitively using linguistic variables. In contrast, mathematical optimization approaches typically are not able to cope with diffuse sets, whereas neural networks are highly complex and may have problems with variations and non-deterministic communication characteristics. Moreover, by considering the inherent constraints of wireless sensor networks like limited battery power and the imprecise characteristics of the radio link, the use of fuzzy logic rules seems to be the most efficient heuristic model [12].

3. Proposed Handoff Mechanism

This Section presents the WSN models, a snapshot of the handoff procedure and an insight of the use of fuzzy logic in the handoff heuristics. Then, the two phases of the proposed handoff procedure are described.

3.1. WSN Model

Handoff decision can be made in a distributed (managed at the mobile nodes) or centralized (managed by a single node, e.g. the sink) way. The centralized approach may become less effective for large scale WSNs, as the communication burden between mobile nodes and the central node may lead to unacceptable message delays (for an effective real-time handoff), extra traffic load and energy consumption. For this reason, we opted for distributed handoff management – the mobile nodes take the responsibility of managing handoff, just interacting with the neighbor access points. Figure 2 illustrates our generic WSN model in which nodes may be static (SN) or mobile (MN) and are somehow associated to access points (APs) that enable WSN nodes connectivity with the rest of the WSN.

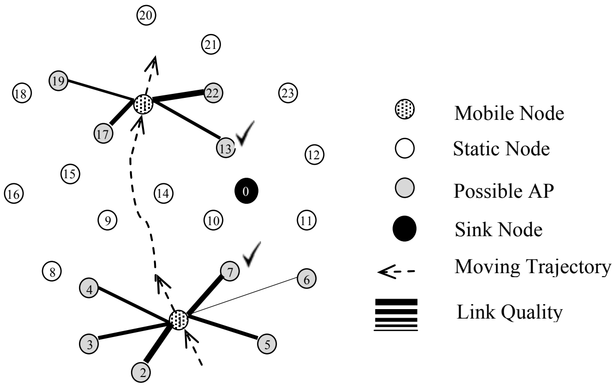

Figure 2. Network Model

We assume different types of time or frequency scheduling between groups/clusters of APs and associated WSN nodes, as to avoid message collisions between adjacent groups/clusters. In this paper we only focus on the handoff heuristic, thus other specifics such as groups/clusters scheduling, (re)routing/(re)addressing and mobility patterns are not under scope of this work. When a mobile node (MN) is moving from the coverage area of an access point (AP_{old}) to the coverage area of another access point (AP_{new}) with a certain speed, the mobile node may learn about the possibility of changing into another cell by a degradation of the signal quality in terms of received signal strength of AP_{old}, and so triggering the handoff mechanism. Depending on the WSN model under consideration using frequency division or time division multiple access between adjacent groups/clusters, probe requests should be sent in different frequency channels or in specific time slots in such a way to guarantee that a MN assesses all the neighboring APs. This handoff model is proposed for a generic network model and it does not focus on a specific model such as FDMA or TDMA. In case of having an FDMA-based model, each node transmits data on a locally unique frequency channel, and in TDMA-based model, nodes communicate using specific time slots.

3.2. Overview of the Proposed Handoff Procedure

As already referred, in most wireless network protocols handoff is based just on the RSS value. In the proposed approach, handoff is based on RSS level, velocity of mobile node, AP depth level (number of hops to sink node), and some other metrics such as traffic load, energy level and link quality value. Any link quality estimation mechanism can be utilized, but the F-LQE (Fuzzy Link Quality Estimator) [13] has been selected, because it has shown a better performance compared to other LQEs as it inherently combines several link quality metrics.

The proposed handoff procedure is composed of two phases: 1) initial assessment of the need for handoff; 2) handoff.

The first phase (described in Section 3.3) aims at deciding whether to do handoff or not, trying to avoid unnecessary handoffs. A MN sends periodic probe messages to its current AP, expecting some acknowledgement message (ACK). It then infers the need for handoff from the RSS average of the acknowledgement messages and from the speed of the MN, if available. If the decision is to handoff, the MN moves to the second phase of the handoff procedure.

In the second phase, the quality of the radio link between the MN and the available neighbouring APs is assessed using the F-LQE link quality estimator [13]. Additionally, the handoff heuristic is enriched by taking into consideration other characteristics of the APs, such as their energy level, traffic load, and depth level.

Figure 2 illustrates a mobile node (1) in two different times - t_0 and t_n. Our example is not concerned with two consecutive handoff procedures other than that it shows two distinct handoff decisions. The link quality is represented by a solid line (the thicker, the better). At time t_0, the mobile node detects six alternative SNs that can be chosen as its next AP. In this case, node 7 and node 2 have more chances to be selected as the next AP, since they have the highest link quality. There are more decision factors in the proposed handoff algorithm such as energy level and traffic load, as it will be discussed in the following sections. For instance, since node 7 is only one hop away from the sink node, it is more likely to be selected as the AP. Now consider time t_n in which the mobile node detects four alternative APs. As it is shown in the figure, node 17 and node 22 have the highest link quality but their location may affect their chances of being selected as the next AP. In contrast node 13 with medium link quality which is closer to the sink has higher priority of being the next AP. These two examples show the importance of different input parameters in various situations. It can be concluded that there is a trade-off between different input parameters and a node with the strongest link quality or smaller number of hops to the sink is not always the best choice.

3.3. On the Use of Fuzzy Logic

Fuzzy Logic is an alternative methodology which can be used in the design of both linear and non-linear systems for embedded control. Fuzzy logic provides a rigorous algebra for dealing with uncertainty. It is expressed in a mathematical discipline invented to express human reasoning with mathematical notations. By this approach the two cases of true and false in conventional algebra are converted to more relaxed conditions, which can help to combine different objectives to achieve an optimal solution. This technique seems to be an efficient alternative for handoff decision making in wireless sensor networks.

A comprehensive theory of fuzzy logic can be found in [14]. The general concept of fuzzy logic is introduced next. By definition, let U be a collection of objects and be called the universe of discourse. A fuzzy set $F \in U$ is characterized by a membership function $\mu_F(u): U \rightarrow [0,1]$ where $\mu_F(u)$ represents the degree (or grade) of membership of $u \in U$ in the fuzzy set F. Therefore, the variables that are used as input parameters are defined by a membership value. This mechanism is used in both phases of the proposed handoff procedure when using fuzzy logic.

3.4. Handoff Mechanism (Phase One)

We define some notations with reference to Figure 3, which shows a handoff from the current AP, referred as AP$_{\text{old}}$, to the future AP, referred as AP$_{\text{new}}$.

The S_{th} level is the threshold value of the RSS to initiate the handoff process. Therefore, when the RSS level of AP$_{\text{old}}$, referred to as RSS$_{\text{old}}$ drops below S_{th}, the handoff is triggered. The $S_{\min}$, indicates the minimum value of RSS required for successful communication between a MN and the AP$_{\text{old}}$ with a certain probability (let us say 95%). The maximum transmission range of each AP is denoted by a. Hence, as the figure illustrates, the handoff mechanism must be completed before the RSS of AP$_{\text{old}}$ drops below $S_{\min}$, i.e., before the MN moves beyond the coverage area of AP$_{\text{old}}$.

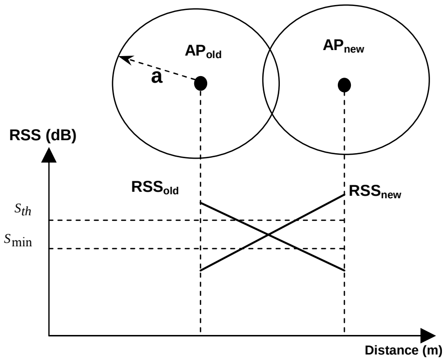

Figure 3. Analysis of Handoff in Phase One

The first phase of the handoff procedure is illustrated in the algorithm of Figure 4. The connectivity between MN and the current AP is assessed by averaging the RSS value from probe acknowledgement messages.

A MN sends periodic (T_{probe}) probe requests which are to be acknowledged by the current AP. Upon the reception of the probe acknowledgements, the MN computes the average of the last θ RSS values ($\overline{RSS}$). Parameter θ should be set low enough to enable a quick assessment of the radio link (the higher θ, the longer it takes) and high enough to attenuate (by averaging) too sudden fluctuations of the RSS. We use a short window to calculate the mean RSS (e.g. θ = 5). The computation of T_{probe}, which is a function of the mobile node's velocity and the radio coverage/overlapping of the APs, is left out of this paper.

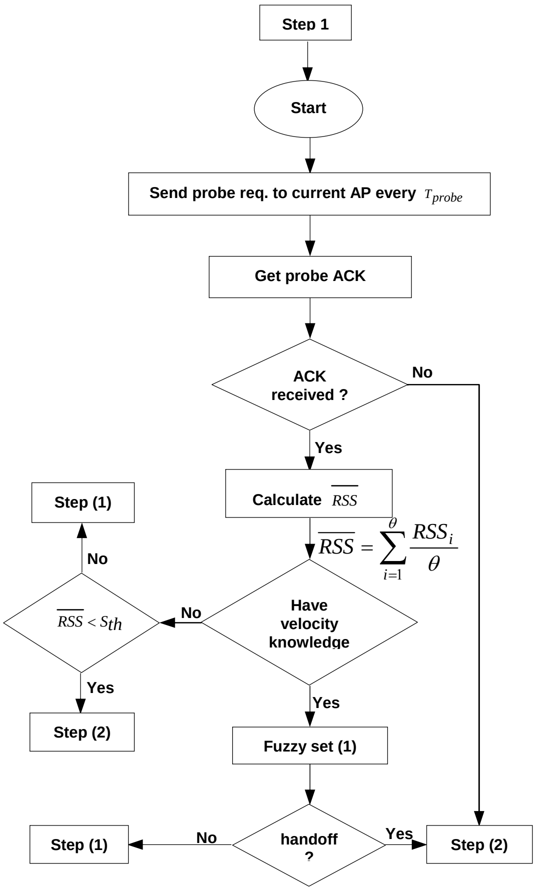

Figure 4. Handoff Mechanism (Phase One)

If there is no information on MN's speed, the $\overline{RSS}$ is compared with S_{th}. If the mean received signal strength has dropped below this threshold then the handoff should be performed, otherwise it continues sending probe requests. In case the MN knows its velocity, either predefined or estimated, a fuzzy logic set getting both $\overline{RSS}$ and velocity values is computed. If the result of this rule indicates to (try to) associate to another AP, then the MN should pass to the second phase of the algorithm.

The basic configuration of the fuzzy logic system is shown in Figure 5 and consists of four principal elements: fuzzifier, fuzzy handoff rule, fuzzy interface engine (handoff decision making unit), and defuzzifier.

The fuzzifier performs a mapping from the observed crisp input space, e.g. the measured RSS, to the membership of the fuzzy set, e.g. high RSS, where a fuzzy set is characterized by a membership function. The handoff fuzzy rule consists of a set of linguistic rules in the form of "IF a set of conditions are satisfied, THEN a set of sequences are inferred". The fuzzy inference engine is a decision making logic which employs fuzzy rules from the handoff fuzzy rules unit to map the fuzzy sets in the input space. Finally, the defuzzifier performs a mapping from the fuzzy sets to crisp points. The output of the defuzzifier is generally a crisp value, calculated by using fuzzy logic operators.

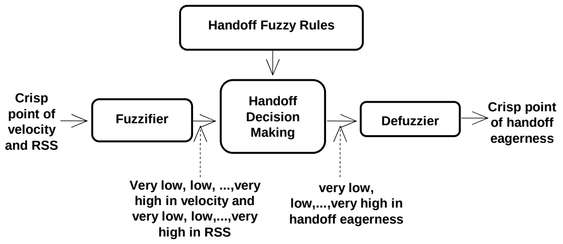

Figure 5. Fuzzy Logic System Unit in Details

Table 1. Fuzzy Rule

Velocity	RSS	Handoff Eagerness
Very low	Very low	Very high
Very low	Low	High
Very low	Medium	Medium
Very low	High	Very low
Very low	Very high	Very low
low	Very low	Very high
low	Low	High
low	Medium	Medium
low	High	Low
low	Very high	Very low
Medium	Very low	Very high
Medium	Low	High
Medium	Medium	Medium
Medium	High	Low
Medium	Very high	Very low
High	Very low	Very high
High	Low	Very high
High	Medium	High
High	High	High
High	Very high	High
Very high	-	Very high

The input fuzzy variable of speed and RSS are assigned to one of the five fuzzy sets, "*very low*", *"low"*, *"medium"*, *"high"* or *"very high"*, which are optionally classified into five levels. This grouping strategy gives more clues on the weakness and strength of input variables and helps generating more accurate output data. Table 1 illustrates the eagerness of performing handoff depending on the velocity and RSS levels. For example, when the value of velocity is "*very high*" and the value of RSS is "*very low*"; this condition indicates that handoff should be encouraged immediately or the handoff eagerness is "*very high*". We define the handoff in cases of having "*high*" or "*very high*" eagerness in output.

3.5. Handoff Mechanism (Phase Two)

By getting handoff permission in the first phase, the MN moves to second phase of the handoff procedure. The handoff decision will be based on a more accurate estimation of the radio link quality (using F-LQE, rather than just RSS) between an MN and all AP in its vicinity, and on AP-specific parameters such as the traffic load, depth and energy level.

Similarly to the first phase, as it is illustrated in Figure 6 and explained previously, probe requests are periodically sent every T_{probe} on available channels or time slots (according to FDMA or TDMA schemes). By receiving probe acknowledgements from neighbouring APs, the algorithm enters the decision making phase.

The process of choosing the best AP between several alternatives can impact WSN performance. Hence, it is important to obtain reliable and accurate link quality estimation in a short time. Link quality estimators (LQEs) have been proved to provide a more accurate and stable information on link quality than just RSS [15]. We opted for F-LQE [13], since it has recently been shown to perform better than existing LQEs. It advocates combining several important link properties to get a holistic characterization of the link. It uses fuzzy logic to estimate the link quality. Therefore, by defining link properties in linguistic terms and performing the fuzzy logic rule, it results the degree of membership of the link in the fuzzy subset of good quality links.

In this design, four link quality metrics of packet delivery, asymmetry, stability and channel quality are considered. The goodness or high quality of a link is characterized by the following rule: "**IF** the link has high packet delivery AND low asymmetry AND high stability AND high channel quality **THEN** it has high quality." By use of and-like compensatory operator of [13], the following equation stands for link i with high quality:

$$\begin{aligned}\mu(i) = \beta.\min(\mu_{SPRR}(i), \mu_{ASL}(i), \mu_{SF}(i), \mu_{ASNR}(i)) + \\ (1-\beta).mean(\mu_{SPRR}(i), \mu_{ASL}(i), \mu_{SF}(i), \mu_{ASNR}(i))\end{aligned} \quad (1)$$

The membership function $\mu(i)$ in equation (1) represents the membership to the fuzzy set of high quality links and the others like $\mu_{SPRR}(i), \mu_{ASL}(i), \mu_{SF}(i)$ and $\mu_{ASNR}(i)$ indicate the membership functions in the fuzzy subsets of high packet delivery, low asymmetry, low stability, and high channel quality respectively. The parameter β is a constant value in range [0,1]. By considering $LQ(w) = 100.\mu(i)$, the link score range changes to [0..100], where 100 denotes the best link quality and 0 shows the worst. Equation (2) shows the F-LQE value after performing EWMA filter for smoothing:

$$FLQE(\alpha, w) = \alpha.FLQE + (1-\alpha).LQ \quad (2)$$

Where $\alpha = 0.9$ to provide a stable link estimate, and w is the estimation window, meaning that a node estimates link quality based on each w received packets.

In order to choose the appropriate AP, we consider other criteria apart from link quality estimation. These criteria are energy level (EL), traffic load (TL), and depth level (DL). Each criterion is considered as a fuzzy variable and is supposed to be embedded in the payload of the probe acknowledgement messages. The following equation shows the membership function of fuzzy handoff (FHO) for mobile node n :

$$\mu_{FHO}(n) = \gamma.\min(\mu_{FLQE}, \mu_{TL}, \mu_{EL}, \mu_{DL}) + (1-\gamma).mean(\mu_{FLQE}, \mu_{TL}, \mu_{EL}, \mu_{DL}) \qquad (3)$$

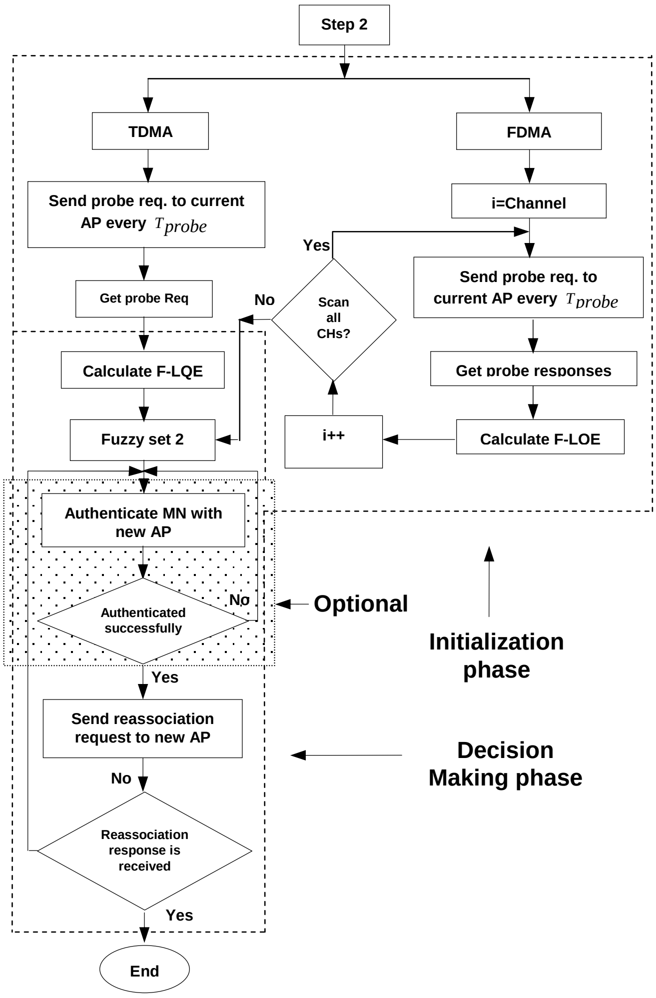

Figure 6. Handoff Mechanism (Phase Two)

The constant value of γ should be defined/tuned according to future simulation/experimental results. Afterwards, an optional authentication phase is performed by sending an authentication request by MN and getting the response from the AP. Finally, the mobile node sends a reassociation request to the new AP. The handoff mechanism ends when the MN receives the association ACK message.

4. Final Remarks

This paper outlines a reliable handoff procedure for supporting mobility in WSNs. A two-phase procedure is proposed that performs handoff decision according to several important metrics, combining them using fuzzy logic.

Next step is to implement, test and validate the proposed handoff mechanism via simulation and experimental models. This will enable to tune the different parameters of the handoff heuristics for an optimal handoff.

We are planning to implement and integrate the proposed handoff mechanism in standard WSN protocols such as ZigBee and 6LoWPAN, to demonstrate its feasibility and efficiency.

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