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INTUITIONISTIC FUZZY DETECTION OF SIGNAL AVAILABILTY IN MULTIPATH WIRELESS CHANNELS

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Abstract
This article develops an intuitionistic fuzzy estimation of the availability of a radio signal from a mobile unit to the base station in a shadowing and multipath propagation environment. This estimation method provides a way to optimally manage the switching strategy of the base station depending on the signal level of the different mobile units served by that base station.

Index terms - *Intuitionistic fuzzy sets, multipath channels.*

Introduction

In mobile communication systems a base station serves several mobile units in its coverage area (cell). In order to allocate resources optimally, the base station estimates the received signal power from the mobile units. For example, if the signal power drops below a certain threshold level of minimum power, the corresponding mobile unit has to be disconnected to release the current channel for use by another mobile unit that needs a channel in the cell. Also, in systems like those based on the wideband code division multiple access (WCDMA) standard [1] certain cell sizes with corresponding threshold levels are defined to provide faster connection speeds for higher power levels.

As the mobile unit moves, the signal level experiences slow variation due to many obstacles blocking the signal within the radio propagation environment [2]. Due to the slow variation there is a fraction of time when the signal is available, and a fraction of time when the signal is not available above a certain threshold level. The signal level experiences also fast fluctuation as the mobile unit moves due to many propagation paths of the radio signal. The different paths add to produce constructive and destructive interference. This fluctuation places the signal rapidly in and out of the availability region and is too fast for the base station to perform any effective switching action regarding the signal availability.

For handling this kind of a situation, an intuinitionistic fuzzy set (IFS) framework [3] is proposed. The IFS approach has been used in evaluation of communication links [4, 5, 6]. Here, it will be used to detect the signal availability above a certain threshold level in presense of signal variation and rapid fluctuation.

Signal Variation and Fluctuation

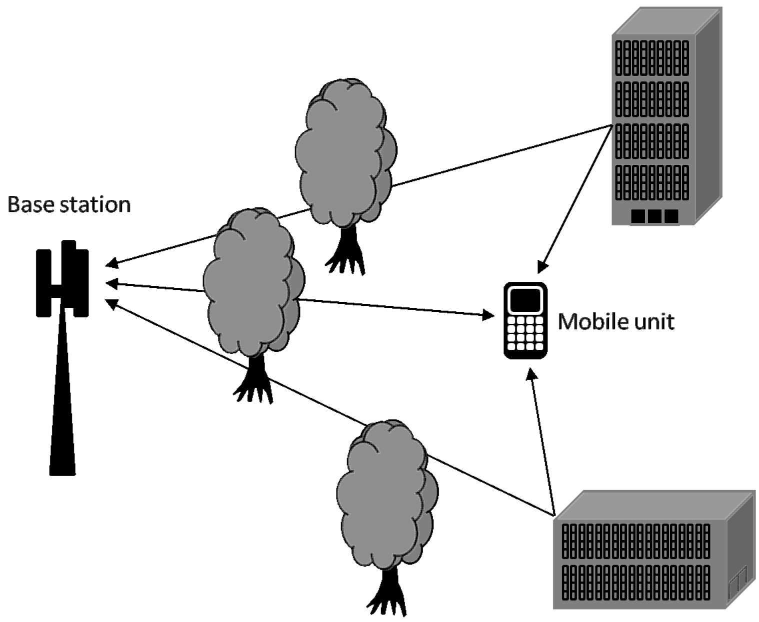
The signal power level drops because of three major factors: *path loss*, *shadowing* and *multipath propagation*. The path loss is a deterministic dependence of the signal strength at the receiver versus the distance from the transmitter. The shadowing is caused by blocking the signal power at some places and concentrating it at other places by randomly placed obstacles within the region, covered by the transmitter. The signal variation due to shadowing occurs over distances on the order of the size of the surrounding objects and this is why this kind of variation of the signal strength is also called *large-scale fading*. The multipath propagation is caused by scattering of the transmitted signal on its way to the receiver, so the receiver gets different replicas of the transmitted signal with different scaling coefficients and phase shifts. The different replicas add to produce a constructive and destructive interference. As a result, the signal strength fluctuates over distances on the order of the wavelength and this is why this kind of fluctuation of the signal level is also called *small-scale fading*. In mobile communications the traveled distance $\boldsymbol{d}$ is transformed to an elapsed time $\boldsymbol{t}$ by the well known dependence $\boldsymbol{d} = \boldsymbol{vt}$, with $\boldsymbol{v}$ being the mobile unit velocity, and the large-scale and small-scale fading become *long-term* and *short-term* fading, respectively. A typical radio propagation channel is shown in Fig. 1(a).

The mean signal level depends on the distance of the mobile unit to the base station through the path loss mechanism. Superimposed on the mean level of the signal at the given distance is the variation due to shadowing. Then, when the signal level drops below a certain level $\boldsymbol{P_t}$ as shown in Fig. 1(b) with the thick line representing the shadowing variation, the base station performs some kind of a switching action (drops the call, changes the transmission rate, etc.). Superimposed on the slow variation is the fast signal fluctuation due to the multipath fading. The mltipath signal fluctuation is also shown in Fig. 1(b).

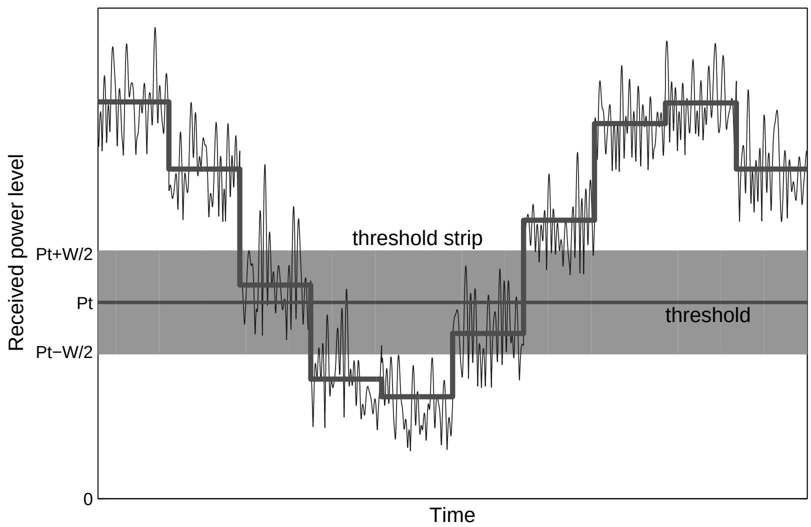
Intuitionistic Fuzzy Sets

The IFS theory has been developed in [3] as a generalization of the ordinary fuzzy set theory [7]. As an extension to the conventional Boolean set theory with its two possible values, true and false, the fuzzy set theory handles values that are partially true - partially false. In claassical set theory the membership of an element to a given set is assessed by an indicator function that can be either 0 for non-membership, or 1 for membership. By constrast, in the fuzzy set theory the membership of an element to a given set is assessesd by a membership function that can take any real value in the interval $[\mathbf{0}, \mathbf{1}]$. This membership function, denoted by $\boldsymbol{\mu}$ is termed degree of membership. The complement of the membership function to 1, denoted by $\boldsymbol{\nu}$, is termed degree of non-membership. Both $\boldsymbol{\mu}$ and $\boldsymbol{\nu}$ can take real values in the interval $[\mathbf{0}, \mathbf{1}]$, such that $\boldsymbol{\mu} + \boldsymbol{\nu} = \mathbf{1}$. In the classical set theory either $\boldsymbol{\mu} = \mathbf{1}$ and $\boldsymbol{\nu} = \mathbf{0}$, or $\boldsymbol{\mu} = \mathbf{0}$ and $\boldsymbol{\nu} = \mathbf{1}$.

The IFS theory further generalizes the ordinary fuzzy set theory by allowing the degrees of membership and non-membership not necessarily add up to 1, so that $\boldsymbol{\mu}+\boldsymbol{\nu} \leq \mathbf{1}$. The complement of the sum of the degrees of membership and non-membership to 1, denoted by $\boldsymbol{\pi}$, is termed degree of uncertainty about membership or non-membership. All the three degrees $\boldsymbol{\mu}$, $\boldsymbol{\nu}$ and $\boldsymbol{\pi}$, can take real values in the interval $[\mathbf{0}, \mathbf{1}]$, such that



(a) Shadowing and multipath



(b) Signal variation

Figure 1: The radio propagation channel in mobile communications.

$\mu + \nu + \pi = 1$. In the ordinary fuzzy set theory $\pi = 0$.

Signal Availability Detection

The signal is declared unavailable when the its power drops below a threshold level P_t and stays below that level. The combined action of the path loss and shadowing determines a relatively slow variation of the signal level as the mobile unit moves within the cell. Thus, the signal is not available or unavailable all the time, but is available a fraction of the time and unavailable the rest of the time. Such a detection can be modeled with an ordinary fuzzy set with the metric $0 \leq \mu(P_t) \leq 1$ representing the signal availability above the threshold P_t, and the metric $\nu(P_t) = 1 - \mu(P_t)$ representing the signal unavailability above that level. Note that when the mobile unit is not in motion, the wireless connection is fixed and in an otherwise static channel the signal is either available or not available all the time. Therefore, in a static wireless channel the signal availability detection becomes a problem of the classical set theory with either $\mu(P_t) = 1$ and $\nu(P_t) = 0$, or $\mu(P_t) = 0$ and $\nu(P_t) = 1$.

In addition to the slow variation determined by the path loss and the shadowing, the signal also fluctuates rapidly due to the multipath fading. Using the ordinary fuzzy set framework to detect the signal availability above the threshold level when the current signal level is near the threshold, the base station has to perform switching actions each time the signal drops below the threshold, thus making the communication process too ineffective. The proposed solution is to use an intuitionistic fuzzy estimation of the signal availability, definng a threshold *strip* with a width W symmetrically around the threshold instead of the single threshold P_t. Within the strip the signal is declared neither available or unavailable, that is, there is *uncertainty* about the signal availability. In the IFS approach the elements $0 \leq \mu(P_t, W) \leq 1$, $0 \leq \nu(P_t, W) \leq 1$ and $\pi(P_t, W) = 1 - \mu(P_t, W) - \nu(P_t, W)$ are used respectively for detecting the fading signal availability when the signal power level is above $P_t + \frac{W}{2}$, unavailability when the signal power level is below $P_t - \frac{W}{2}$, and uncertainty about the signal availability when the signal power level is between $P_t - \frac{W}{2}$ and $P_t + \frac{W}{2}$. The element $\pi(P_t, W)$ represents the uncertainty whether the signal is available or not available above the threshold level P_t based on the current observation of the instant signal power. The threshold strip width W determines the degree of uncertainty and is chosen so that the essential peak-to-peak rapid fluctuation falls within W. This means that a larger signal fluctuation due to multipath fading corresponds to a larger degree of uncertainty about the signal availability above the threshold level P_t.

The base station performs measurement of the received signal power in discrete time instants. During a communication between a base station and a mobile unit there are three possibilities:

1. The signal level is available above the threshold P_t;
2. The signal level is unavailable above the threshold P_t;
3. The mean signal level is near the threshold the threshold P_t and the signal fluctuates around that threshold.

These estimates of the time fraction of signal availability (μ) and the signal unavailability (ν) are represented by ordered pairs $\langle \mu, \nu \rangle$ of real numbers from the set $[0,1] \times [0,1]$. The fraction of the uncertainty $\pi = 1 - \mu - \nu$ represents the cases when the signal fluctuates around the threshold level P_t. The ordered pairs are defined in the context of intuitionistic fuzzy sets mentioned above.

At first, the estimate is given initial values of $\langle 0, 0 \rangle$. For the discrete time index $k > 0$, the current $(k+1)$-st estimate is calculated based on the previous estimates according to the recurrence relation

$$\langle \mu_{k+1}, \nu_{k+1} \rangle = \langle \frac{\mu_k k + m}{k+1}, \frac{\nu_k k + m}{k+1} \rangle \tag{1}$$

where $\langle \mu_k, \nu_k \rangle$ is the previous estimation, and $\langle m, n \rangle$ is the most recent estimation, for $m, n \in [0,1]$ and $m + n \leq 1$. Thus the final estimation is based on the previous and the latest level of the signal.

Four values are defined, M_{max}, M_{min}, N_{max}, N_{min}, so if $\mu > M_{max}$ and $\nu < N_{max}$ then the signal is available above the threshold level and if $\mu < M_{max}$ and $\nu > N_{max}$ then the signal is not available above the threshold level. The rest of the time when the signal level is not clearly defined needs an additional approach to decide about the availability. A possible solution would be the availability decision to be the same as the previous certain decision (either available or unavailable).

Conclusion

This paper introduces intuitionistic fuzzy estimation of the signal availability above a defined threshold level in mobile communications. It is shown that the intuitionistic fuzzy set framework is naturally suited for capturing the fast signal fluctuation around its current level. For larger peak-to-peak fluctuation of the received signal, the degree of detection uncertainty becomes proportionally larger. This kind of detection has the potential to optimize the switching actions of the base station serving the mobile units whose signal power levels are measured by that base station.

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