# Bluetooth and IEEE 802.11 Coexistence Service Architecture with Fuzzy-based Switching Scheme


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*Abstract*

*In the modern world of wireless communications, the concept of wireless global coverage is of the utmost importance. Based on the concept, a two-tier service architecture with fuzzy-based switching scheme was proposed in an IEEE 802.11 (WLAN) and bluetooth (WPAN) coexistence network environment. In the environment combined resources are allocated to new/handoff services according to some acceptance criterion and service facility such as motion speed and traffic characteristics. Through the fuzzification, de-fuzzification and inference procedures, a switching decision-making scheme was performed. Simulation results were shown that the performance in terms of service blocking probability, system utilization from the fuzzy-based two-tier model, which experiences a severe radio mutual interference had better than that of homogeneous networks at 26% and 3.5%, respectively. The service interworking performance in terms of end-to-end delay was also measured. The seamless roaming function can be developed to expand the scope of wireless users and densely populated wireless LAN in the proposed architecture.*


## 1. Introduction

The past several years have been exciting for wireless communications and, thereby, a dramatic increase in the short-range transmission media which is shown in Figure 1. The objective of wireless communications systems is to provide users radio access to services comparable to those currently offered by the fixed infrastructure, resulting in a seamless convergence of both fixed and mobile services [1]. The explosion of technological alternatives and the commercialization of IEEE 802.11 WLAN standards have stimulated much public interest [2].

Short-range radio technology, named Bluetooth, is expected to become widespread on Wireless Personal Area Networks (WPAN) discussed in the IEEE 802.15 Working Group in the future [3]. Bluetooth technologies have potentially much to ensure that the best services and quality are delivered and system resources are used efficiently. The bluetooth specification had defined how bluetooth-enabled devices could access service of IP networks using the IETF *PPP* Protocol [4]. By mapping IP addresses on the corresponding bluetooth device (BT) addresses (BD_ADDR), the access across Internet is enabled.

WLANs typically cover ranges from ten to a few hundred meters. Because LANs often are used for relatively high-capacity data communications, they often have fairly high data rates. This combination of coverage and data rate leads to moderate-to-high power consumption. WPAN cover a Personal Operation Space (POS: 10 meters in all directions) and used to mobile appliances without using cables. Small clustered office piconets will facilitate the entire printer and disc. This peer-to-peer device communication does not usually require exceedingly fast data rates. This short range and relatively low rates result in low power consumption.

WLAN and WPAN wireless communications both take place in the 2.4 GHz band, thus, inevitably interfere with each other when used in the same place at the same time. WPAN and WLAN may overlap with each other but offer specifically different costs and benefits. Some manufacturers are already investigating into the combination of both technologies in dual-mode devices like TrueRadio system of Mobilian, Blue802 technology of Silicon Wave, and so forth. We studied that show that either technology performance degradation when subjected to normal (or even extreme) interference from the other. Based on the traffic characteristics, network features and user behavior, a fuzzy-based switching scheme was performed here to make decision for new/handoff services as far as the overlap of technologies goes.

In the next section, we introduce different types of internetworking mechanism. In Section 3, we describe the radio mutual interference problem between WLAN and WPAN service networks. The switching system based on fuzzy set theory for new/handoff call admission is described in Section 4. Some selected representative

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simulation results are presented in Section 5. Finally, Section 6 summarizes the research.

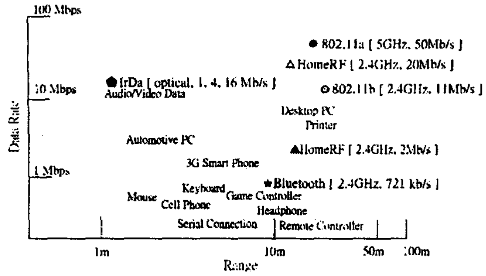
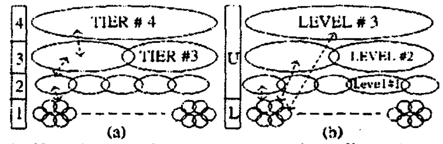



**Figure 1. Short-range wireless communications media [5]**

## 2. Existing coexistence mechanisms

Multitier wireless access could be enabled by network intelligence that supports the interconnection of a variety of wireless networks. By using multiple wireless access modes that are optimized for different types of venues, multitier wireless access should be able to achieve high performance with low cost and usage rates that approach those of wired service.

Numerous studies have been done to construct multitier/multilevel access systems as well as interference issues [6]. These systems are broadly classified into two categories- strictly hierarchical model and homogeneous overlay model, shown in Figure 2. In the right side of Figure 2, called homogeneous overlay model, the cellular system consisting of two levels with microcell in the lower-level and multiple sub-levels of macrocell in the upper-level, is considered to separately serve mobiles with different speeds [7]. Integration of macrocell and microcell seems to be a relevant method in the next generation of cellular systems, where higher traffic must be accommodated with a minimum effort of investment. Each system has its own benefits and deficiencies and mobile users need to carefully select the system best fits their mobile communication requirements. However, many mobile users may require services from more than one mobile systems (heterogeneous systems), e.g. cellular systems for outdoor and cordless systems for indoor (see the left side of Figure 2) [8]. The development of new systems is usually to complement the services provided by existing systems rather than to replace them, so integrate various mobile systems to form a multitier environment is the easiest and fastest way to fulfill the requirement of most users.




U: Upper Layer L: Lower Layer <--->: handoff direction

**Figure 2. Different types of multi-tier access systems**

IEEE 802.15.2 working group and the Bluetooth SIG make efforts to define mechanisms and recommended practices to facilitate coexistence of WLAN and WPAN devices [9,10]. Coexistence mechanisms fall into two classifications:

- Collaborative mechanisms
  A WLAN device and a WPAN device require to be collocated when applied these techniques, and furthermore collocated systems can communicate and collaborate to minimize mutual interference. Manual switching, Driver layer switching and MAC layer switching are related collaborative techniques.
- Non-collaborative mechanisms
  There is no direct communication for the both networks to communicate. WLAN modifies its data rate and packet size, adaptive power control and adaptive frequency hopping are Non-collaborative techniques being investigated.

In this research, the AFH (Adaptive Frequency Hopping) scheme was implemented on the baseband layer to provide robust coexistence capability to WPAN-WLAN environment. The associated details of AFH scheme will be discussed in the next section.

## 3. Interference analysis

IEEE 802.11b uses Direct Sequence Spread Spectrum (DSSS) of high-power transmissions and doesn't hop to other channels like Frequency Hopping Spread Spectrum (FHSS). Each channel is defined by its center frequency and ranged with each other at intervals of 5MHz. Since there are 22MHz-wide overlapping channels in the 2.4 GHz ISM band, it would result in interference when using adjacent channels in the same location. Three wireless networks collocate together and operate on channel 1, 6 and 11 is the best channel selection to prevent overlapping and maximum frequency channel utilization.

Bluetooth uses FHSS of low-power transmission with 1600 hops per second. Bluetooth devices hop over 79 1MHz-wide frequency channels. The manner, Bluetooth device avoids IEEE 802.11b interference on its hopping channel at present time slot is hopping to the other channel and re-transmitting again at the next time slot. The drawbacks of this manner are the throughput degradation on ACL (Asynchronous Connection Link) data transmission and packets lost when using SCO (Synchronous Connection-Oriented) links because these links don't utilize ARQ mechanism.

### 3.1. Non-collaborative coexistence mechanism

IEEE 802.15 Working Group delivers Personal Area Network standards for short distance wireless networks. To solve the frequency interference problem between IEEE 802.11b and Bluetooth, the Adaptive Frequency Hopping (AFH) mechanism written in -01/252r0 to modify the baseband frequency hopping sequence in Bluetooth module was proposed [9].

### 3.2. Performance analysis

In Figure 3, it is the original frequency hopping sequence. Hopping sequence will hop on the 79 channels between 2.4GHz to 2.483GHz. With AFH mechanism to baseband hopping, hopping rule will modify the hopping sequence to the remainder channels (79–22) excluded IEEE 802.11b hopping channels from channels 0 to 21 (only one Access Point; 1 *AP*). The AFH-based hopping sequence result on 1 *AP* is shown in Figure 4.

The hopping sequence with AFH mechanism on three IEEE 802.11b *APs* environment are shown in Figure 5. It was found that the hopping channels become scarce. However, the interference problem will be serious while the *APs* are more than four (see Figure 6). Hence, the converged service area is at most three IEEE 802.11b *APs* in our research. Other services outside the converged area are connected to Internet or bluetooth networks by using IEEE 802.11a interface whose operating environment is in 5.8GHz band.

## 4. Proposed fuzzy-based switching scheme

In this section, some basic fuzzy set theory concepts are reviewed for the development of proposed mechanism. Following that, the approach will be explained in detail.

### 4.1. Fuzzy sets and linguistic variables

In 1973, Professor L.A. Zadeh proposed the concept of linguistic variables [11]. Linguistic variables can be thought of as linguistic objects, rather than numbers. A fuzzy set can be viewed as the generalization of a crisp set in that it allows a degree of membership for each element to range over the unit interval [0,1]. Therefore, the membership function maps each element of the universe to its interval range, [0,1]. A fuzzy set $F$ in $U$ may be represented as the set of ordered pairs of a generic $u$ and its grade of membership function: $F=\{(u, u_F(u))|u\in U\}$.

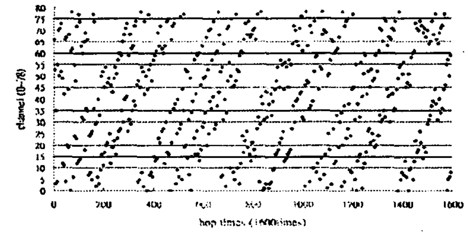


**Figure 3. Frequency hopping without AFH mechanism**

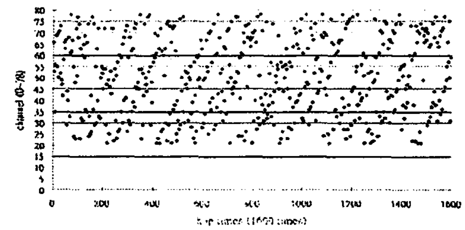


**Figure 4. Frequency hopping with AFH mechanism (1 *AP*)**

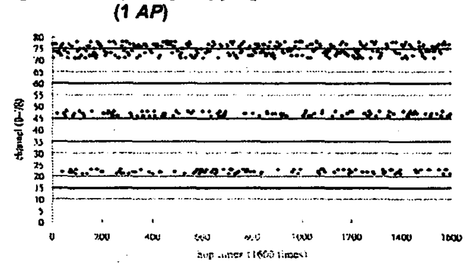


**Figure 5. Frequency hopping with AFH mechanism (3 *APs*)**

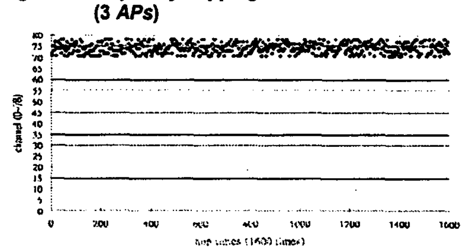


**Figure 6. The interference problem (4 *APs*)**

The notion central to a fuzzy system is that membership value, which is indicated by a value in the range [0.0,1.0], with 0.0 representing absolute Falseness and 1.0 representing absolute Truth. It is important to note that two operations, UNION (OR) and INTERSECTION (AND), which represents the clearest point of departure from a probabilistic theory for sets to fuzzy sets. These two operations are utilized to support our approach.

C = A UNION B, where: $\mu_C(x) = \mathrm{MAX}(\mu_A(x), \mu_B(x))$

C = A INTERSECTION B, where: $\mu_C(x) = \mathrm{MIN}(\mu_A(x), \mu_B(x))$

### 4.2. Concepts of fuzzy logic controller (*FLC*)

Fuzzy Logic is a departure from classical two-value sets, that uses "soft" linguistic (e.g. large, hot, tall) system variables and a continuous range of truth-values in the interval [0,1], rather than strict binary (True or False) decisions. Simple, plain-language **IF** *X* **AND** *Y* **THEN** *Z* rules are used to describe the desired system response in terms of linguistic variables rather than mathematical formulas. The operation is dependent upon the relationship of inputs, outputs, and the designer's control response goals. The *FLC* architecture is shown in Figure 7.

The fuzzification interface performs the fuzzification function that covers input data into suitable linguistic values, which may be viewed as fuzzy set labels. The knowledge base comprises knowledge of the application domain and the attendant control goals. This consists of a data base and a linguistic control rule base. The decision making logic is the kernel of an *FLC*. The *FLC* has the capability of simulating human decision-making based on fuzzy concepts and inferring fuzzy control actions employing fuzzy implications and the inference rules in fuzzy logic. Several inference methods are defined such as *MAX-MIN, MAX-PRODUCT, ROOT-SUM-SQUARE, and AVERAGING* methods. The defuzzification interface performs scale mapping, which converts the range of values of the output variables into the corresponding universes of discourse.

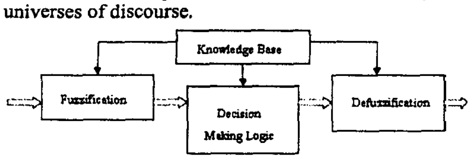



**Figure 7. The *FLC* architecture**

### 4.3. Design of fuzzy model in our approach

In a fuzzy model, choosing suitable linguistic values to present the input and output variables and select the membership functions to identify the application domain is very important. In this study, we utilized MOVE_VELOCITY and DATA_RATE as the input parameters (see Figure 8). MOVE_VELOCITY is a factor of the user's movement, which is navigated by the linguistic values of the moving velocity from the specified mobile subscriber. DATA_RATE is an index with respect to the traffic characteristic. This characteristic is identified according to the traffic types.

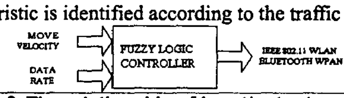



**Figure 8. The relationship of input/output operation**

The membership functions we utilized are the popular $\Pi$ and $S$ functions. The fuzzy sets for MOVE_VELOCITY take the linguistic variables "*Very_Slow*", "*Slow*", "*Medium*", "*Fast*" and "*Very_Fast*" referring to the mobile subscriber's moving velocity. Five possible fuzzy subsets for moving velocity space X are represented in *Appendix A* by the membership functions *VS*(x), *Sl*(x), *Me(x)*, *Fa(x)* and *VF(x)*, respectively.

In a similar way, the fuzzy sets for DATA_RATE are the linguistic variables "*Very_High*", "*High*", "*Medium*", "*Low*" and "*Very_Low*" referring to the traffic characteristic with respect to the new/handoff services. Five possible fuzzy subsets for visiting frequency space Y are represented in *Appendix B* by membership functions *VL*(y), *Lo*(y), *Me*(y), *Hi(y) and VH(y)*, respectively.

To arrive at a crisp output value that gives a decision of allocated service media relative to an active mobile subscriber, an output parameter called the SERVICE_COVERGENCE, was defined. The universe of discourse for the SERVICE_COVERGENCE is over the interval [0,1]. A crisp value close to 1.0 interpreted as making high suggestion for WLAN, while a value close to 0.0 communicates the opposite (WPAN). The fuzzy linguistic variables for SERVICE_COVERGENCE are "*High*", "*Medium*" and "*Low*" which are represented by the membership functions *Hi(z)*, *Med(z)* and *Lo(z)*, respectively. The space *Z* is referred to as the confidence factor for a target WLAN. After the defuzzification process, the target WLAN mapped in Z values in the universes of discourse that are greater than the defined threshold, will be decided in our research.

The input and output fuzzy sets were correlated to produce the fuzzy rules formulated as **IF** *X* **AND** *Y* **THEN** *Z* for the inference engine illustrated in Figure 9. An example corresponding to the fuzzy rules and mobile service is shown in Figure 10.

Rule (1): IF MOVE_VELOCITY = "Very_Fast" AND DATA_RATE = "Very_High"
THEN SERVICE_COVERGENCE = "High" (WLAN)
Rule (2): IF MOVE_VELOCITY = "Very_Fast" AND DATA_RATE = "High"
THEN SERVICE_COVERGENCE = "High" (WLAN)
Rule (3): IF MOVE_VELOCITY = "Very_Fast" AND DATA_RATE = "Medium"
THEN SERVICE_COVERGENCE = "High" (WLAN)

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Rule (13): IF MOVE_VELOCITY = "Medium" AND DATA_RATE = "Medium"
THEN SERVICE_COVERGENCE = "Medium" (WLAN & WPAN)
Rule (14): IF MOVE_VELOCITY = "Medium" AND DATA_RATE = "Low"
THEN SERVICE_COVERGENCE = "Medium" (WLAN & WPAN)

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Rule (23): IF MOVE_VELOCITY = "Very_Slow" AND DATA_RATE = "Medium"
THEN SERVICE_COVERGENCE = "Medium" (WLAN & WPAN)
Rule (24): IF MOVE_VELOCITY = "Very_Slow" AND DATA_RATE = "Low"
THEN SERVICE_COVERGENCE = "Low" (WPAN)
Rule (25): IF MOVE_VELOCITY = "Very_Slow" AND DATA_RATE = "Very_Low"
THEN SERVICE_COVERGENCE = "Low" (WPAN)

**Figure 9. The sampled fuzzy rules in our approach**

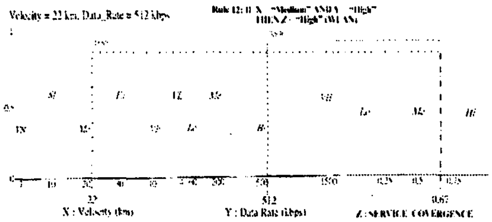

Figure 10. An example for inference procedure

### 4.4. Proposed scheme

In this sub-section, we will show our mechanism, the Fuzzy-Matrices Switching Scheme (*FMSS*), in detail. The *FMSS* flow chart is illustrated in Figure 11. The *FMSS* scenarios are described in the following.

**Step 1: Fuzziness and 1st Allocation**

When a mobile host will initiate a service, the mobile host's moving velocity is predicated and data rate is estimated using the MOVE_VELOCITY and DATA_RATE linguistic values in the first measurement period. Based on these linguistic values, a suitable wireless communication media is selected and service is made by the selected media. Service coverage selection, based on the fuzzy matrices, is formulated using the following.

- Based on the problem domain, the subjective Membership Function (MF) is illustrated in Appendix A and Appendix B.
- The mobile host's moving velocity and the service's data rate are estimated using the MOVE_VELOCITY and DATA_RATE linguistic values. Using the moving velocity, traffic rate and the above MF, whose membership grades are over the predefined threshold, can be allocated to WLAN service network. A set of example is listed in Tables 1-3.

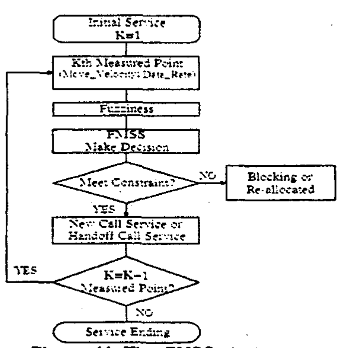


Figure 11. The *FMSS* strategy

Table 1. The example for moving velocity estimation

| Linguistic value of the MOVE_VELOCITY | MF Grade | | | | | (MF Grade >= 0.7) |
|---|---|---|---|---|---|---|
| | VS | Sl | Me | Fa | VF | MF allocation |
| 0.5km | 1 | 0.216 | 0.061 | 0.027 | 0 | VS |
| 7km | 0.222 | 0.735 | 0.128 | 0.045 | 0 | Sl |
| 18km | 0 | 0.28 | 0.862 | 0.147 | 0 | Me |
| 33km | 0 | 0.045 | 0.128 | 0.735 | 0.18 | Fa |
| 48km | 0 | 0.017 | 0.03 | 0.071 | 1 | VF |

Table 2. The example for data rate estimation

| Linguistic value of the DATA_RATE | MF Grade | | | | | (MF Grade >= 0.7) |
|---|---|---|---|---|---|---|
| | VL | Lo | Me | Hi | VH | MF allocation |
| 6kbps | 0.777 | 0.033 | 0.062 | 0.01 | 0 | VL |
| 56kbps | 0 | 0.862 | 0.107 | 0.012 | 0 | Lo |
| 200kpbs | 0 | 0.005 | 1 | 0.027 | 0 | Me |
| 512kbps | 0 | 0 | 0.025 | 0.945 | 0 | Hi |
| 1578kbps | 0 | 0 | 0.001 | 0.002 | 0.903 | VH |

Table 3. The example for the service allocation

| MOVE_VELOCITY / DATA_RATE | Resource allocation | | | | |
|---|---|---|---|---|---|
| | 0.5km | 7km | 18km | 33km | 48km |
| 6kbps | P | P | W/P | W | W |
| 56kbps | P | P | W/P | W | W |
| 200kpbs | P | W/P | W/P | W | W |
| 512kbps | W/P | W/P | W | W | W |
| 1578kbps | W | W | W | W | W |

W: WLAN, P: WPAN, W/P: Both

**Step 2: Conflict Resolution**

If the inferred result is not only one communication media suitable for service, that is, both WLAN and WPAN are suitable for the service. In this case, the best performance (i.e. system utilization, blocking probability) is an index negotiated by the subscriber and service provider.

*Step 3: Allocation Again*

Using the new measured MOVE_VELOCITY and DATA_RATE linguistic values, the coverage area is estimated again. The step 1 and 2 process is continuous until the service is turned off.

## 5. Performance analysis

To investigate our approach, a performance analysis of both the homogeneous networks (pure WLAN and pure WPAN) and *FMSS* mechanisms was performed in our laboratory. The simulation results in terms of service blocking probability and system utilization are drawn in Figs. 11 and 12, respectively. We can see that the *FMSS* scheme mean blocking probability is better than that of WLAN at 25.91% and at 149.88% for WPAN when new call rate is 20 calls/second. It is also better than homogenous networks at 3.5% in system utilization. The service interworking performance in terms of end-to-end delay was also measured. The result is shown in Figure 13.

## 6. Conclusion

In this paper, a fuzzy-based mechanism applied to the service convergence for a multi-tier wireless communications system was discussed. From the simulation results, the performance of the proposed *FMSS* scheme is better than the pure WLAN or WPAN service systems. We also measure the service interworking performance. Our study indicated that the proposed scheme could significantly reduce the mean blocking probability and increase the system utilization compared with other approaches at expense of a small switching complexity.

## 7. Acknowledgement

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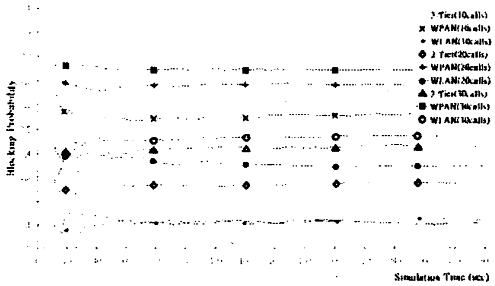

Figure 11. The analysis of blocking probability

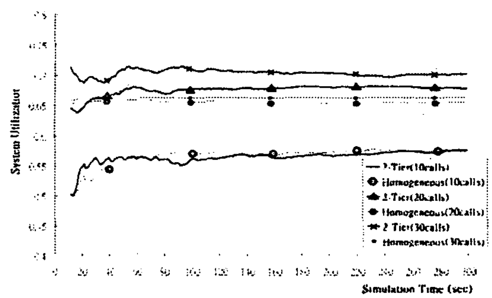

Figure 12. The analysis of system utilization

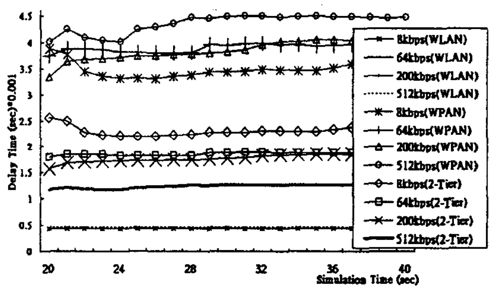


Figure 13. The analysis of end-to-end delay

**Appendix A. Five possible fuzzy subsets for moving velocity space X**

| MF | Velocity Description | Speed Range |
|---|---|---|
| VS(x) | Stationary, walk | $VS(x)=\begin{cases}1, & \text{when } x<1\\ 1-2\left(\frac{x-10}{9}\right)^2, & \text{when } 1\le x<5.5\\ 2\left(\frac{x-1}{9}\right)^2, & \text{when } 5.5\le x<10\\ 0, & \text{when } x\ge 10\end{cases}$ |
| Sl(x) | Movement with low speed manpower equipment | $Sl(x)=\begin{cases}0, & \text{when } x\le 0\\ \frac{1}{1+\left(\frac{x-10}{5}\right)^2}, & \text{when } 0<x<20\\ 0, & \text{when } x\ge 20\end{cases}$ |
| Me(x) | Movement with high speed manpower equipment | $Me(x)=\begin{cases}0, & \text{when } x\le 10\\ \frac{1}{1+\left(\frac{x-20}{5}\right)^2}, & \text{when } 10<x<30\\ 0, & \text{when } x\ge 30\end{cases}$ |
| Fa(x) | Vehicle with normal speed | $Fa(x)=\begin{cases}0, & \text{when } x\le 20\\ \frac{1}{1+\left(\frac{x-30}{5}\right)^2}, & \text{when } 20<x<40\\ 0, & \text{when } x\ge 40\end{cases}$ |
| VF(x) | Vehicle with high speed | $VF(x)=\begin{cases}0, & \text{when } x<30\\ 2\left(\frac{x-30}{10}\right)^2, & \text{when } 30\le x<35\\ 1-2\left(\frac{x-40}{10}\right)^2, & \text{when } 35\le x<40\\ 1, & \text{when } x\ge 40\end{cases}$ |

**Appendix B. Five possible fuzzy subsets for data rate space Y**

| MF | Data Description | Data Rate Range |
|---|---|---|
| VL(y) | Remote control signal | $VL(y)=\begin{cases}1, & \text{when } y<4\\ 1-2\left(\frac{y-4}{6}\right)^2, & \text{when } 4\le y<7\\ 2\left(\frac{y-10}{6}\right)^2, & \text{when } 7\le y<10\\ 0, & \text{when } y\ge 10\end{cases}$ |
| Lo(y) | Transmission of audio and data for 2.5G-3G smartphone or PDA | $Lo(y)=\begin{cases}0, & \text{when } y\le 40\\ \frac{1}{1+\left(\frac{y-60}{20}\right)^2}, & \text{when } 40<y<80\\ 0, & \text{when } y\ge 80\end{cases}$ |
| Me(y) | Transmission of picture and printed document | $Me(y)=\begin{cases}0, & \text{when } y\le 100\\ \frac{1}{1+\left(\frac{y-200}{50}\right)^2}, & \text{when } 100<y<300\\ 0, & \text{when } y\ge 300\end{cases}$ |
| Hi(y) | Normal rate mode of ADSL and cable services | $Hi(y)=\begin{cases}0, & \text{when } y\le 400\\ \frac{1}{1+\left(\frac{y-500}{50}\right)^2}, & \text{when } 400<y<600\\ 0, & \text{when } y\ge 600\end{cases}$ |
| VH(y) | High rate mode of ADSL and cable services | $VH(y)=\begin{cases}0, & \text{when } y<1400\\ 2\left(\frac{y-1400}{200}\right)^2, & \text{when } 1400\le y<1500\\ 1-2\left(\frac{y-1600}{200}\right)^2, & \text{when } 1500\le y<1600\\ 1, & \text{when } y\ge 1600\end{cases}$ |