



Trends in  
**Applied Sciences  
Research**

ISSN 1819-3579



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## **Intelligent Vertical Handover Scheme for Utopian Transport Scenario**

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### **ABSTRACT**

Intelligent Transportation System (ITS) needs an “always best connected” communication to ensure vehicular safety. ITS is an application of 4G which is characterized by heterogeneous radio access networks. The heterogeneous co-existence of access technologies with largely different characteristics creates a decision problem for determining best available network at a point of time. A context aware intelligent vertical handover algorithm for vehicular communication is presented here. The proposed work, studies the implementation of an intelligent vertical handover scheme based on Analytic Hierarchy Process (AHP) and fuzzy decision process. The priorities of the factors which play an influencing role in the handover process is calculated using the concept of AHP and the decision algorithm for handover is developed using the fuzzy rules based on the priorities obtained from AHP. The uses of fuzzy takes into account the uncertainty that may arise for minor difference of the priorities and hence helps to make the system more robust. A case study has been presented to demonstrate the effectiveness of this model and the selection of the optimum network with the varying speed of the vehicle in the utopian environment. The results show that the presented model not only realistically optimizes the best available network on the move but also avoids unnecessary handovers. This algorithm is specific to vehicular communication system and hence variation in network selection with vehicle speed is shown. Simulation work has been carried out in the MATLAB environment.

**Key words:** Vertical handover, intelligent transportation system (ITS), software defined radio (SDR), cognitive radio, analytic hierarchy process (AHP), fuzzy logic, context repository, adaptability manager

### **INTRODUCTION**

Reduction in road accident casualties is now the part of national strategy in most of the countries. The primary objective of Intelligent Transportation System (ITS) is to provide safety to human lives and improve the security, efficiency and comfort of the transportation system. To achieve this goal, Intelligent Transportation System (ITS) converges remote sensing and communication technologies. Moreover, demand for voice, data and multimedia services, while moving in car, increase the importance of Broadband wireless systems in ITS (Huang, 2006).

Safety applications and non safety applications are the two major categories of ITS applications. Adaptive Cruise Control (ACC), Driver Assistance Systems (DAS) and Collision avoidance and warning systems (CAWAS) are some examples of safety application. On the other hand, internet

access from car, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication (Gozalvez and Sepulcre, 2007), satellite television from car, radio taxi and automatic toll collection are categorized as non-safety applications.

International Telecom Union (ITU) and International Organization for Standardization (ISO) have promoted a new family of ITS standards with the overall branding of “Continuous Air-interface for Long and Medium range (CALM)”. The aim of CALM is to provide wide area communications to support ITS applications that work equally well on a variety of different network platforms.

The development of the future Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications systems imposes strong radio channel management challenges due to their decentralized nature and the strict Quality of Service (QoS) requirements of traffic safety applications. An intelligent, Network independent handoff which is also known as vertical handoff, decision algorithm is important for a seamless “Always Best Connected” (ABC) vehicular communication.

In homogeneous networks, horizontal handovers (between different cells of the same network) are typically required when the serving access router becomes unavailable due to mobile terminal's movement. In heterogeneous networks, the need for vertical handovers (between different types of networks) can be initiated for convenience rather than connectivity reasons (e.g., according to user choice for a particular service). Two of the major challenges in vertical handover management are seamlessness and automation aspects in network switching. These particular requirements can refer to the Always Best Connected (ABC) concept, of being connected in the best possible way in an environment of multiple access technologies, according to policies (expressed by rules based on parameters such as network conditions or user preferences) (Gustafsson and Jonsson, 2003).

The deployment of various wireless technologies (3G, WLAN, WiMAX, etc.) in combination with the modern and advanced Mobile Terminals (MTs) with multiple network interfaces and the development of IP-based applications (non-real-time or real-time) has allowed the user to have access to IP services anywhere at anytime from any network. This is the vision of fourth Generation (4G) of wireless communications (McNair and Zhu, 2004; Frattasi *et al.*, 2005; Kim and Prasad, 2006; Korhonen, 2003). This next-generation of wireless systems represents a heterogeneous environment with different access networks technologies that differ in bandwidth, latency or cost. In this kind of environment, mobility management is the essential issue that supports the roaming of users from one system to another. Handover management, one of the mobility management components, controls the change of the MT's point of attachment during active communication (Akyildiz *et al.*, 2004).

For that, a handover management technique must choose the appropriate time to initiate the handover and the most suitable access network for a specific service among those available, and must maintain service continuity.

In the context of future wireless networks, the literature survey reveals that none of the vertical handover schemes were proposed specific to a transport scenario. This research shows the context aware vertical handover scheme and focuses on decision problem in vehicular communication environment. In general a vertical handover is basically a decision making process which selects as to where to handover in heterogeneous network. In this study, the decision criteria include user preferences, network conditions, application requirements and terminal capabilities, all these are evaluated and compared, to detect and to trigger a vertical handover. The research shows that how advanced multi criteria decision tools like AHP (Analytic Hierarchy Process) and soft computing tools like fuzzy logic can be used to solve such a problem and thus answering ABC requirement.

## HANDOVER MANAGEMENT IN HETEROGENEOUS WIRELESS NETWORKS

The key aspect for supporting mobility scenarios is the handover management. It is the process by which mobile terminal maintains its connection active while moving from one point of attachment (base station or access router) to another. The handover management concept features: mobility scenarios, handover process, types, control and performance.

Many works describe the handover process in three phases:

- **Handover information gathering:** The information required to identify the need for handover are collected. Handover will be initiated on the basis of this information. This stage can also be called handover initiation phase
- **Hand over decision:** This stage determines whether and how to perform the handover by selecting the most suitable access network (taking into account some criteria such as user preferences) and by giving instructions to the execution phase. It is also called network selection
- **Handover execution:** Result of the decision phase is executed in this stage

## REQUIREMENT FOR RECONFIGURABLE HARDWARE

As both communications and computing technology advanced, it was inevitable that the two continue to integrate, defining the field known today as Software Defined Radio (SDR) (Rondeau and Bostian, 2009). Communication devices are increasingly putting signal processing capabilities into software. SDR provides many advantages and improvements in waveform design. SDRs offer flexibility and hardware re-configurability which make the better use of the available communication system. To achieve the seamless connectivity it is necessary to re-configure the communication system's hardware based on the decision of the handover management system.

Mitola and Maguire (1999) and Mitola (2006) is credited with inventing the field of cognitive radios (Doyle, 2009; Haykin, 2005) with an interest in using the radio system as a personal assistant of sorts that intelligently reacts to the user's perceived needs. The concept of cognitive radios has since evolved towards a more communications-centric view of the radio. With a reconfigurable SDR system, a cognitive radio uses sensors to collect environmental information as well as an intelligent core (cognitive engine) to react to changes and challenges provided by the environment and user needs. A cognitive radio reacts and adapts to changes in the environment to provide continuous communications at a required quality of service (QoS).

The context aware intelligent vertical handover algorithm presented in this paper is a step towards the development of a cognitive engine to be implemented in next generation cars.

## LITERATURE REVIEW

Vertical handover/handoff is a mandatory requirement to implement CALM and it is the vision of 4G (Kim and Prasad, 2006; Korhonen, 2003; Dhar *et al.*, 2010a). A review of vertical handover decision algorithms are discussed by Sun (2007), Ei and Furong (2008) and Dhar *et al.* (2010b). A robust algorithm should ensure good Quality of Service (QoS) irrespective of physical environment (Lee *et al.*, 2006; Eshanta *et al.*, 2009). QoS depends on the type of application, i.e., conversational, streaming and interactive applications require different bandwidth, delay, jitter etc. A right vertical handover decision algorithm by determining the "best" network at "best" time among available networks based on dynamic factors such as "Received signal strength (RSS)" of network and "velocity" of mobile station simultaneously with static factors like usage expenses, link

capacity and power consumptions is presented by Goyal and Saxena (2009). Ei and Furong (2010) has developed a trajectory aware vertical handoff protocol for handover between WiMAX and 3G. Importance of mobile station velocity and movement pattern is considered by Lee *et al.* (2007). Competitive and cooperative relationships among the major ITS communication technologies, WiMax, WLAN and WCDMA, are considered by Ma and Jia (2005). Sabrie and Salleh (2009) have proposed a handoff enhancement technique using IAPP. Leni and Srivatsa (2008) have presented a handoff technique to improve TCP performance. An Analytic Hierarchy Process (AHP) based network selection algorithm for UMTS and WLAN is presented by Song and Jamalipour (2005a). Along with WCDMA and WLAN, DVB-H which supports both data and broadcast services correspondingly, is explained by Seo *et al.* (2007). In study of Sun *et al.* (2008), the vertical handoff decision problem is formulated as a Constrained Markov Decision Process (CMDP). A two step, i.e., a pre-handoff decision algorithm followed by a handoff decision algorithm is presented by Hwang *et al.* (2007). An AHP based comparison of different vertical handoff algorithms is presented by Stevens-Navarro and Wong (2006). An AHP based multi-criteria decision making (MCDM) tool is designed for vertical handover among WLAN, UMTS and GPRS and is presented by Isakson and Fiedler (2007). Measurements of application perceived throughput in DAB, GPRS, UMTS and WLAN is done for automatic network selection in (Chevul *et al.*, 2005). A 3-step network selection strategy for new cell arrival in a road condition is shown by Nitiwong *et al.* (2009). AHP and Grey Relational Analysis (GRA) based network selection mechanism for UMTS and WLAN is presented by Song and Jamalipour (2005b) for next generation networks. Dhar *et al.* (2010c), have proposed an AHP based vertical handover algorithm for intelligent transportation systems. A framework for both horizontal and vertical handover in wireless network based on mobile IPv6 has been proposed by Cheng *et al.* (2005). Handoff triggering and network selection algorithm in CDMA-WLAN integrated networks is proposed and QoS performance against velocity of mobile terminal is discussed by Kim and Prasad (2006). A load balancing vertical handover algorithm which will maximize the collective battery lifetime of Mobile Nodes, is proposed by Lee *et al.* (2009). Context aware vertical handoff algorithms, proposed by Wei *et al.* (2006) and Ahmed *et al.* (2006) introduced a context repository and an adaptability manager for network selection.

After a thorough review of the literature, we conclude with the following criticisms:

- The traditional vertical handover algorithms consider constraint resources but it does not provide the optimal solution for “always best connected” communication for ITS in the context of multiple constraints
- The mathematical formulation of traditional vertical handover is rigorous and needs longer execution time
- Selection of best network against vehicular speed variations is not presented in the traditional vertical handover models as discussed above except in Dhar *et al.* (2010a, b, c)

The vertical handover model, presented here, analyzes the case of a utopian transport scenario in which a vehicle is assumed to pass through the different positions of a highway and the network ranking optimizes the “best” network in multiple constraint environments. This evaluation technique requires knowledge of vehicular speed, Received Signal Strength (RSS), type of application (bandwidth), initial delay for connection establishment, network traffic load and cost of the service.

## PROBLEM DEFINITION

Unlike horizontal handoff, Vertical handoff does not only take place in cell edges. There are many other factors that should be considered for a proper vertical handover. Authors have taken an initiative to develop a cognitive radio (Mitola and Maguire, 1999; Mitola, 2006; Doyle, 2009; Haykin, 2005; Arslan, 2007) based embedded system which will perform both remote sensing and communication for ITS. Software Defined Radio (SDR) based such a system is already presented by Dhar *et al.* (2008) and Bera *et al.* (2008, 2009). Intelligent algorithms are required to upgrade this SDR based system to a Cognitive Radio based system. The aim of this study is to design and simulate a context aware vertical handover among WiMAX, UMTS and WLAN for ITS using AHP-fuzzy tools.

Handover criteria are the qualities that are measured to give an indication of whether or not a handover is needed. We can regroup different criteria as follows:

**Network-related:** coverage, bandwidth offered, latency, network availability (RSS (Received Signal Strength), CIR (Carrier-to-Interferences Ratio), SIR (Signal-to-Interferences Ratio), BER (Bit Error Rate), network traffic load, security level, etc.

**Terminal-related:** velocity, battery power, location information, etc.

**User-related:** user profile and preferences (data rate/bandwidth required), affordable cost for the service.

**Service-related:** monetary cost of service, service capabilities, QoS, etc.

We are taking the following criteria into consideration, in this problem, while selecting the technology on entering a cell having two or more of the above radio access networks available:

- Received Signal Strength (RSS) (Availability of the network)
- Mobility (Speed of the vehicle)
- Data rate/bandwidth (Application)-user preference
- Affordable cost for the service
- Network traffic load
- Initial delay

Suppose the user is moving from a cell to another as shown in Fig. 1.

In typical highway traffic, we have considered three different situations. The position 'A', here the vehicle is in a sub-urban area. Point 'B' is almost similar to point 'A', the vehicle is passing by the toll plaza and about to enter in a city. Thus all three radio networks are available here. Point-C is far from city and only UMTS network is available here.

Point-B, is near to toll plaza and UMTS, WiMAX along with dedicated short range communication (DSRC) network is available here. Currently, the IEEE standard proposed for DSRC, known as 802.11p, is based upon the IEEE 802.11a standard (Tan *et al.*, 2008). The physical Layer of the 802.11p standard is the same as the physical Layer of the 802.11a standard, except for the used sample rate. The main application of 802.11p is vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. DSRC is already in use in USA, Europe and Japan for electronic toll collection (Dhar *et al.*, 2008).

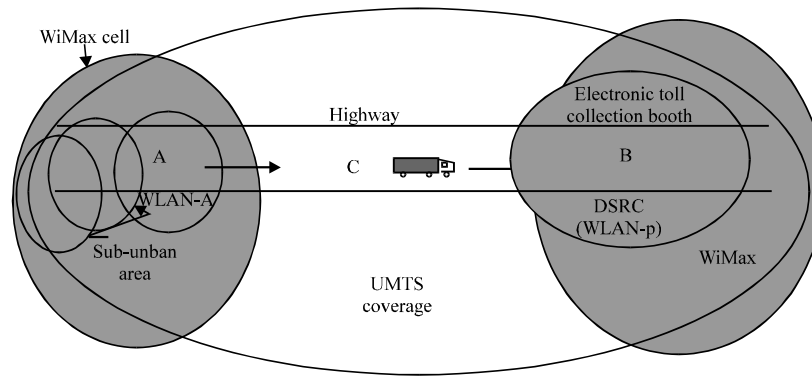


Fig. 1: A Typical Radio Network Availability Scenario for ITS

The applications taken into consideration are Conversational, real time video streaming and real time file transfer (data streaming) (Stevens-Navarro and Wong, 2006). Each of these applications requires a different data rate. All the three technologies do not support these applications with equal QoS. Each wireless technology has a limit on the maximum amount of mobility it can support. As we are considering a transport system speed of the vehicle (mobility) is an important factor to be taken into consideration. WiMAX supports the highest mobility among the three and WLAN has the lowest support for mobility and the least coverage area (Dhar *et al.*, 2008).

Another parameter taken into consideration is the Initial delay, which is the setup time for a connection. Initial delay is more in some systems compared to others. According to Fiedler *et al.* (2005), delay could be up to seven seconds for UMTS. WLAN connectivity, on the other hand, is perceived as responding instantaneously. WiMAX response could be faster than UMTS but slower than WLAN.

Cost of service offered by the particular radio access network is also taken into consideration. Users, if given the option, will always look for lower cost keeping QoS intact; hence a vertical handoff algorithm must try to select the most cost effective network.

## ASSUMPTIONS AND PROPOSED SOLUTION

The following assumptions are made for solving the problem defined in section V.

- Situations of point “A” and point “B” of Fig. 1, where all the three networks are available, are considered for simulation. However, this handover scheme will be valid for any point on the highway
- All the radio access networks will be equally loaded at a given instant. Random network traffic load distribution will be considered in future works
- Two types of applications are considered, viz., conversational/ voice communication and streaming applications (audio, video streaming, internet access, data transfer etc.)

Figure 2 gives our proposed vertical handover functional architecture containing the following given modules.

The context repository module basically a database which collects all the contextual information, through monitoring and measurements, required to identify the need for handover and to apply handover decision. These data are monitored periodically and updated accordingly. All these data are supplied to the adaptability manager.

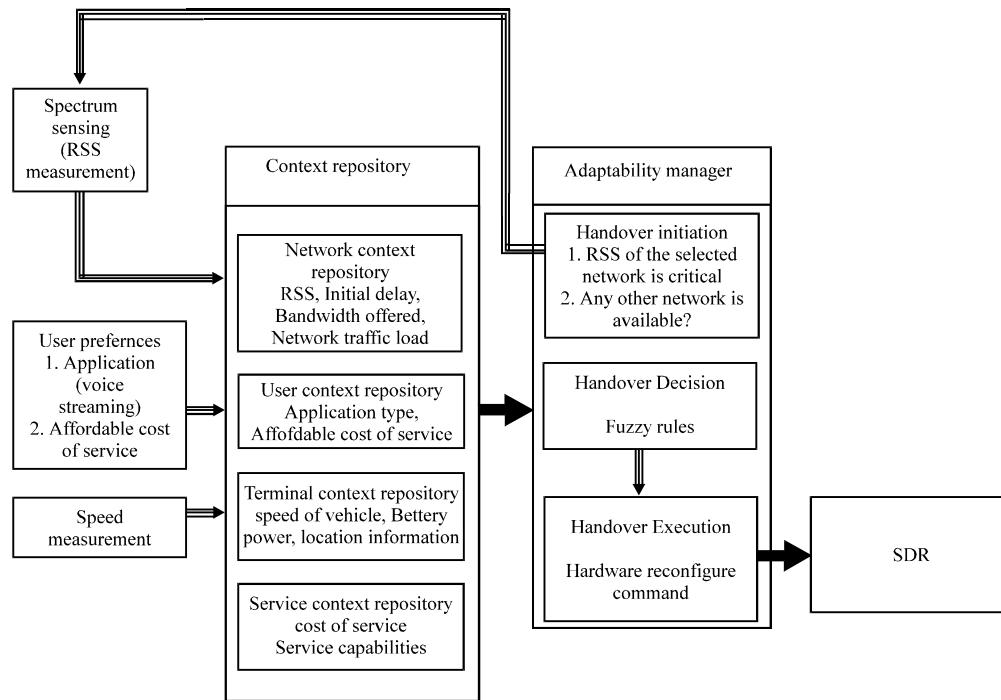


Fig. 2: Functional architecture for vertical handover

**Network context repository:** This holds all the network related contexts. Static parameters like offered bandwidth, initial delay for connection establishment and dynamic data like network availability RSS (Received Signal Strength) and current network traffic load.

**Terminal context repository:** This holds the up to date speed of the vehicle, battery power, location information, etc.

**User context repository:** This accepts the inputs from the user. User preferences are basically the type of application (data rate/bandwidth required) and affordable cost for the service.

**Service context repository:** This stores mainly the static information like monetary cost of service, service capabilities etc.

The Adaptability manager module is responsible for providing transparent switching between networks. So, it encloses the main phases of a handover process: handover initiation, Handover decision (i.e., network selection) and Handover execution. Working of the adaptability manager is explained in the flowchart (Fig. 3).

Handover initiation is a continuous process of RSS and QoS measurement. If either of these two is found critical then spectrum sensing will be started. If any other network is found available then handover process will be initiated else the wireless device will continue the communication through the current radio access network.

Once the handover process is initiated, the gathered context information in context repository will be supplied to the adaptability manager. The optimum network will be selected based on the fuzzy rules. The fuzzy rules are made based on the priorities of the influencing factors obtained using AHP.

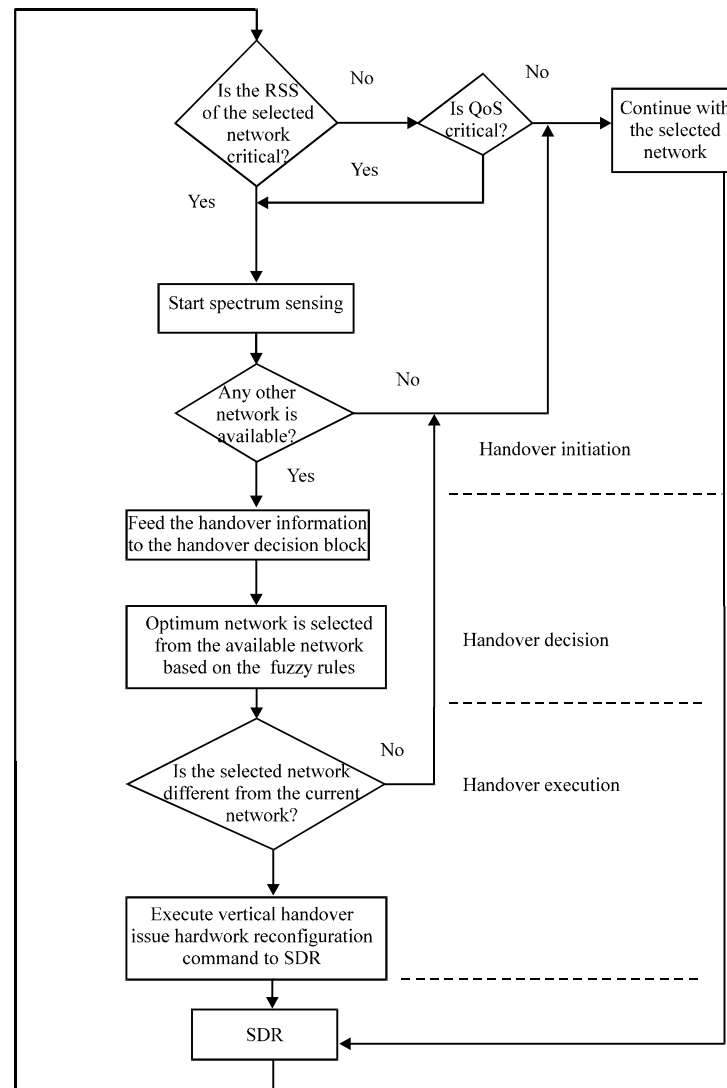


Fig. 3: Working of the adaptability manager

In handover execution phase, the adaptability manager will first check whether the selected network is different from the current network. If so, then it will issue a vertical handover command and will direct the control unit of SDR to reconfigure the hardware according to the selected network.

### ANALYTIC HIERARCHY PROCESS

AHP, developed by Saaty (1980, 1986, 1987, 1988, 1990 and 1994), addresses how to determine the relative importance of a set of activities in a multi-criteria decision problem. The process makes it possible to incorporate judgments on intangible qualitative criteria alongside tangible quantitative criteria. The AHP method is based on three principles:

- Structure of the model
- Comparative judgment of the alternatives and the criteria
- Synthesis of the priorities

Table 1: The nine point scale of pair-wise comparison

Intensity of relative importance	Definition
1	Equally important
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred
2,4,6,8	Intermediate judgment between two adjacent judgments

In the literature, AHP, has been widely used in solving many complicated decision-making problems (Ray *et al.*, 2008a,b; Taha, 2006).

**Step 1:** A complex decision problem is structured as a hierarchy. AHP initially breaks down a complex multi-criteria decision-making problem into a hierarchy of interrelated decision criteria, decision alternatives. With the AHP, the objectives, criteria and alternatives are arranged in a hierarchical structure similar to a family tree. A hierarchy has at least three levels: overall goal of the problem at the top, multiple criteria that define alternatives in the middle, and decision alternatives at the bottom.

**Step 2:** The comparison of the alternatives and the criteria. Once the problem has been decomposed and the hierarchy is constructed, prioritization procedure starts in order to determine the relative importance of the criteria within each level. The pairwise judgment starts from the second level and finishes in the lowest level, alternatives. In each level, the criteria are compared pairwise according to their levels of influence and based on the specified criteria in the higher level. In AHP, multiple pairwise comparisons are based on a standardized comparison scale of nine levels (Table 1).

Let  $C = \{C_j \mid j = 1, 2, \dots, n\}$  be the set of criteria. The result of the pairwise comparison on 'n' criteria can be summarized in an  $(n \times n)$  evaluation matrix 'A' in which every element ' $a_{ij}$ ' ( $i, j = 1, 2, \dots, n$ ) is the quotient of weights of the criteria, as shown:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & \dots & a_{2n} \\ \vdots & \dots & a_{33} & \dots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & \dots & \dots & \dots & a_{nn} \end{bmatrix} \text{ where } a_{ij} = 1, \text{ for } i = j, \text{ and } a_{ij} = \frac{1}{a_{ji}} \text{ for } a_{ij} \neq 0 \dots \quad (1)$$

**Step 3:** the mathematical process commences to normalize and find the relative weights for each matrix. The relative weights are given by the right eigenvector ( $w$ ) corresponding to the largest Eigen value ( $\lambda_{\max}$ ) as:

$$A_w = \lambda_{\max} \cdot w \dots \dots \dots \quad (2)$$

If the pairwise comparisons are completely consistent, the matrix A has rank 1 and  $\lambda_{\max} = n$ . In this case; weights can be obtained by normalizing any of the rows or columns of A.

**Step 4:** Quality of the output of the AHP is strictly related to the consistency of the pairwise comparison judgments. The consistency is defined by the relation between the entries of A :  $(a_{ij} \times a_{jk}) = a_{ik}$ . The consistency index CI is:

$$CI = (\lambda_{\max} - n) / (n - 1) \dots \dots \dots (3)$$

The final Consistency Ratio (CR), usage of which let someone to conclude whether the evaluations are sufficiently consistent, is calculated as the ratio of the CI and the random inconsistency (RI), as indicated.

$$CR = CI / RI \dots \dots \dots (4)$$

The number 0.1 is the accepted upper limit for CR (Saaty, 1980, 1986, 1987, 1988, 1990 and 1994). If the final consistency ratio exceeds this value, the evaluation procedure has to be repeated to improve consistency. The measurement of consistency can be used to evaluate the consistency of decision-makers as well as the consistency of overall hierarchy.

#### PRIORITY CALCULATION OF THE INFLUENCING FACTORS

Availability of the networks (Received signal strength) and bandwidth (Application type) support will act as the triggering factors. Thus the priorities of the other influencing factors using AHP are found here. The factors under consideration are speed of the vehicle, affordable usage cost and network traffic load Table 2.

- The consistency index (CI) = 0.032909
- The consistency ratio (CI) = CI / RI = 0.05674 < 0.1, (RI= 0.58 for n=3 (Ray *et al.*, 2008b))

Hence the AHP matrix is consistent. Priority vector and the consistency ratio are calculated by following the steps.

It is evident from the Table 3, that the 'speed of the vehicle' is the most influencing factor followed by the network traffic load and cost of service for vertical handover scheme in ITS.

Table 2: AHP matrix of the influencing factors

Factors	Speed	Traffic load	Cost
Speed	1	5	7
Traffic load	1/5	1	3
Cost	1/7	1/3	1

Table 3: Normalized matrix of the influencing factors

Factros	Speed	Traffic load	Cost	Priority vector
Speed	0.744681	0.789474	0.636364	0.723506057
Traffic load	0.148936	0.157895	0.272727	0.19318606
Cost	0.106383	0.052632	0.090909	0.083307883

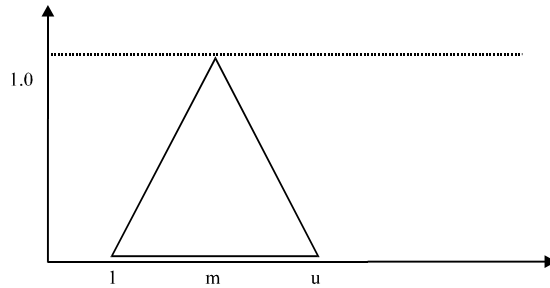


Fig. 4: Triangular Fuzzy Number

### FUZZY SET AND TRIANGULAR FUZZY NUMBER

To deal with vagueness of human thought, Zadeh first introduced the fuzzy set theory which was oriented to the rationality of uncertainty. A major contribution of fuzzy set theory is its capability of representing vague data. A fuzzy set is a class of objects with a membership function ranging between zero and one. It was specifically designed to mathematically represent uncertainty and vagueness. Fuzzy set theory implements groupings of data with boundaries that are not sharply defined (i.e., fuzzy). Any methodology or theory implementing “crisp” definitions such as classical set theory, arithmetic, and programming, may be “fuzzified” by generalizing the concept of a crisp set to a fuzzy set with blurred boundaries. The benefit of extending crisp theory and analysis methods to fuzzy techniques is the strength in solving real-world problems which inevitably entail some degree of imprecision in the variables and parameters measured and processed for the application (Pang, 2007). A triangular fuzzy number (TFN) is the special class of fuzzy number whose membership is defined by three real numbers, expressed as (l, m, u) given in Eq. 5 (Moon and Lee, 1999). Figure 4 displays the structure of a Triangular Fuzzy Number ( $\mu_A$ ).

$$\mu_A = \begin{cases} \frac{x-l}{m-l}, l \leq x \leq m \\ \frac{u-x}{u-m}, m \leq x \leq u \\ 0, \text{otherwise} \end{cases} \quad (5)$$

The operational laws between two triangular fuzzy numbers M1 and M2 are as follows

$$M_1 + M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (6)$$

$$M_1 \times M_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (7)$$

### SIMULATION

The RSS and the application type (voice or streaming) are the critical factors. These factors act as trigger for vertical handover as discussed in section VIII. The information gathered by the context repository (speed of the vehicle, network traffic load, affordable cost), depending on their availability, are fed into the handover decision module which is basically a fuzzifier. Here these parameters are converted into fuzzy sets. A fuzzy set contains varying degree of membership in a set. The membership values are obtained by mapping the values retrieved for a particular variable

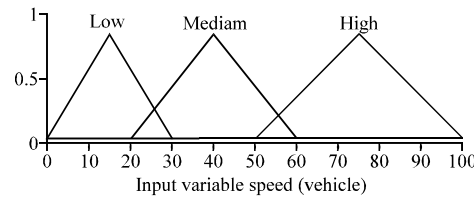


Fig. 5a: Membership function for speed

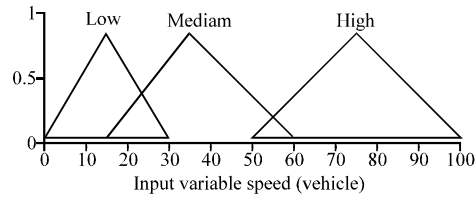


Fig. 5b: Membership function for affordable cost

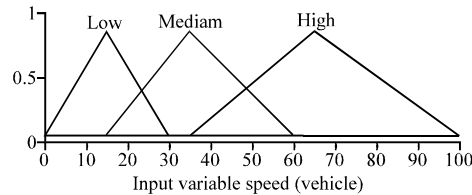


Fig. 5c: Membership function for network traffic load

into a membership function. Figure 5a and b gives membership functions of the input fuzzy variables.

All the three fuzzy variables affordable costs, speed of the vehicle and network traffic load have three fuzzy sets: low, medium and high.

**Affordable cost:**

Low:	0-30%
Medium:	15-60%
High:	50-100%

**Speed of vehicle:**

Low:	0-30 kmph
Medium:	20-60 kmph
High:	50-100 kmph

**Network traffic load:**

Low:	0-30%
Medium:	15-60%
High:	50-100%

After fuzzification, a set of fuzzy rules (Table 4, 5) are applied to determine the rank of different networks. These fuzzy rules are set based on the priorities of the influencing factors as found using AHP. Fuzzy rules utilize a set of IF-THEN rules and the result is Low (signifies a network should not be selected) or High (signifies a network should be selected). As an example from Table 4, the rule 8 represents the case when speed of the vehicle is low, network traffic load is high and user can afford only low cost service then 3G/UMTS should be the selected network.

Table 4: Examples of fuzzy rules (Conversational Application)

Rules	Inputs			Outputs		
	Speed of Vehicle	Network traffic Load	Affordable usage cost	WLAN	UMTS	WIMAX
1	Low	Low	Low	High	Low	Low
8	Low	High	Low	Low	High	Low
15	Medium	Medium	High	Low	Low	High
25	High	High	Medium	Low	High	Low

Table 5: Examples of fuzzy rules (Streaming Application)

Rules	Inputs			Outputs		
	Speed of Vehicle	Network traffic Load	Affordable usage cost	WLAN	UMTS	WIMAX
1	Low	Low	Low	High	Low	Low
8	Low	High	Low	Low	High	Low
16	Medium	High	Medium	Low	Low	High
27	High	High	High	Low	Low	High

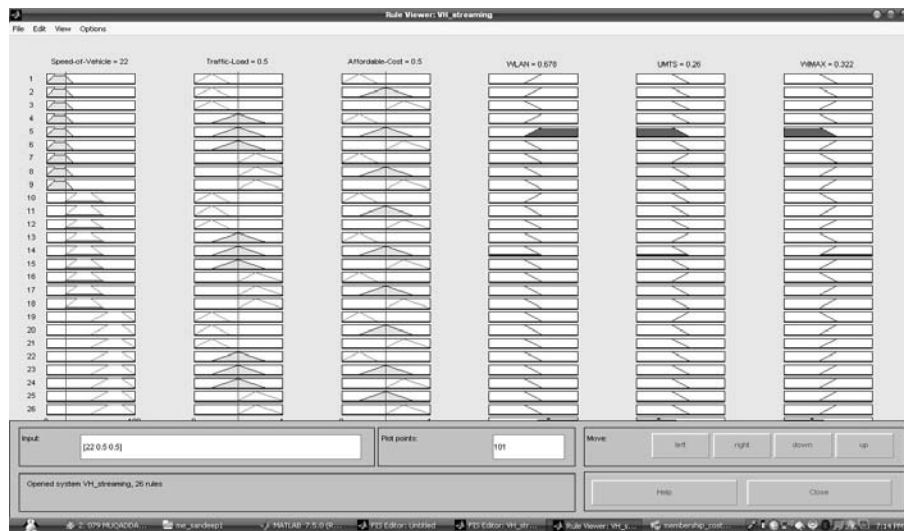


Fig. 6: Network selection using fuzzy rules

## RESULTS

Figure 6 is showing the selection of the optimum network depending on the values of the vehicular speed, traffic load and affordable cost of service. This selection is based on the fuzzy rules. Network with highest selection index will be the chosen network.

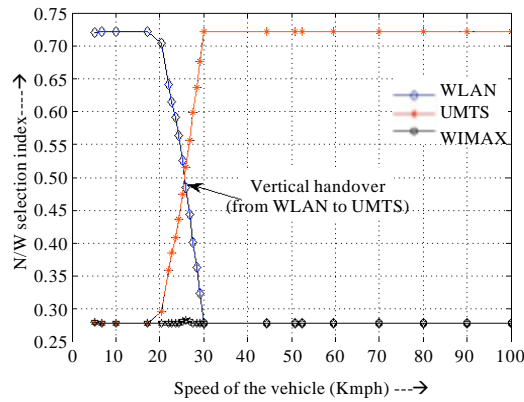


Fig. 7a: Network selection at 35% network traffic and 50% affordable costs

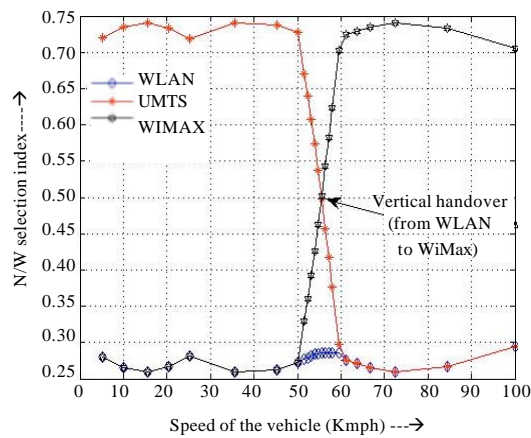


Fig. 7b: Network selection at 70% network traffic and 80% affordable costs

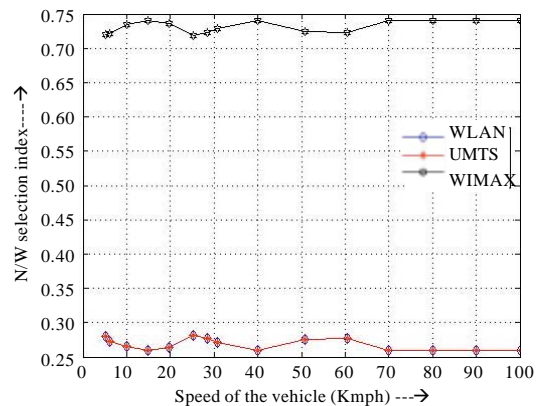


Fig. 7c: Network selection at 35% network traffic and 80% affordable costs

Two types of applications are considered here, viz., voice or conversational application and streaming application (data transfer, audio and video transfer etc.).

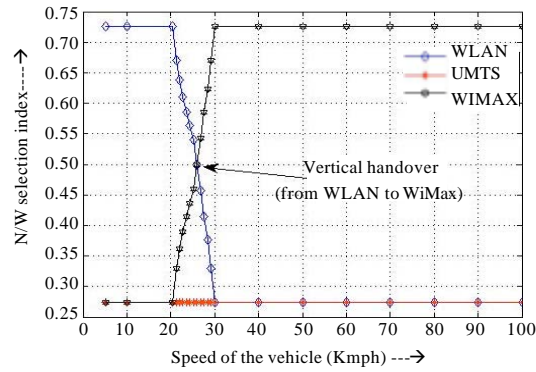


Fig. 8a: Network selection at 35% network traffic and 50% affordable costs

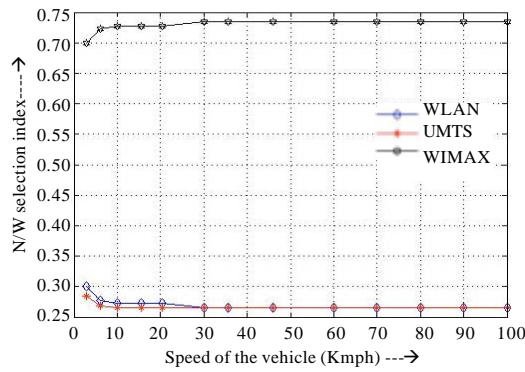


Fig. 8b: Network selection at 70% network traffic and 80% affordable costs

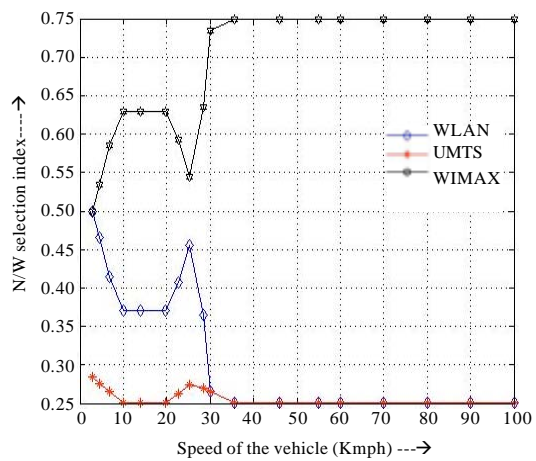


Fig. 8c: Network selection at 70% network traffic and 50% affordable costs

Voice application needs less bandwidth while streaming applications need very high bandwidth. WLAN and WiMAX offer higher bandwidth compared to UMTS. On the other hand, cost of service

is less in UMTS compared to WLAN or WiMAX and UMTS supports much higher network traffic too. Mobility support and coverage of WLAN is poor compared to UMTS and WiMAX.

Figure 7 has presented the network selection with varying speed of vehicle for voice application under different network traffic loads and affordable usage costs.

In Fig. 7a, when network is less loaded and user can afford moderate cost of service, then WLAN is the selected network for low vehicular speed but UMTS is preferred at higher speed. There is a vertical handover situation at around 25 kmph vehicular speed.

Similarly in Fig. 7b, when network is loaded comparatively and user can afford higher usage charges, then up to 55kmph UMTS is the preferred network and beyond this speed WiMAX is preferred. Hence, there will be vertical handover at around 55 kmph vehicular speed. Unlike previous two cases, Fig. 7c depicts a situation, when network load is less and user can afford higher usage charges, WiMAX is always the selected network and thus eliminates the necessity of handover.

Figure 8 has presented the network selection with varying speed of vehicle for streaming application under different network traffic loads and affordable usage costs.

Since the streaming applications require higher bandwidth, thus WLAN and WiMAX are preferred over UMTS. When traffic load is less then WLAN is selected for lower vehicular speed and WiMAX is chosen at higher speed (Fig. 8a). But, if the network traffic load is high, then WiMAX is always preferred (Fig. 8b, c).

## DISCUSSION AND CONCLUSION

In this research, a vertical handover scheme for Intelligent Transportation System (ITS) has been studied. Here, the handover procedure will be initiated only when there will be more than one network available, i.e., RSS will act as a trigger to the handover initiation. Bandwidth requirement depends on the type of application. Therefore, the application type is another triggering factor. Different set of fuzzy rules are formed for two different kinds of applications as shown in Table 4 and 5. AHP is used to prioritize the handover influencing factors and fuzzy rules are set depending on the priorities of different factors.

Thus, selection of the best radio access network can satisfy user requirements anywhere and anytime in a flexible (using policies and context awareness) and efficient manner. In the presented vertical handover decision mechanism, the intelligence and precision have been explored in the whole process for practical mobile terminals. Periodically, the system re-evaluates handover initiation when the mobile user is already using a radio access network. In a case where a handover is needed and there is no better access network available for the ongoing application, system will continue with the current network avoiding subsequent unnecessary handovers (i.e., it avoids ping-pong effect).

The study focuses on the handover decision process which results in the reconfiguration of the hardware. This work is the continuation of the authors' previous work (Dhar *et al.*, 2010a-c; Bera *et al.*, 2008, 2009) where the proposed algorithm was adaptive but not intelligent. Here intelligence is added to the vertical handover decision process using fuzzy logic. The algorithm is tested successfully using MATLAB/SIMULINK simulation and the results are discussed in detail. This program is to be ported in SDR to develop a reconfigurable hardware in future and hence SIMULINK is chosen as the platform for development.

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