An Adaptive Network Selection Algorithm for Smart Grid Communication

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***Abstract* — A key element to realize smart grids is an efficient and reliable communication network. Now smart grids could benefit from a multitude of heterogeneous radio access networks for communications independently of positions. The synergic operation of wireless network is a promising technology, which can improve the efficiency of smart grids significantly. In this paper, a new adaptive network selection algorithm based on technologies of data prioritization classification and data buffer is proposed for assuring ubiquitous communications in smart grids. The priorities are assigned to users depending on their category. Buffers are defined to prioritize high priority data. A dynamic attribute technique is proposed to reflect the situation of the network compared with the conventional Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method, which aims at performing the network selection with high reliable and low delay. Finally, a numerical example is adopted to illustrate the feasibility and practicability of the proposed algorithm. The results highlight the number of handoffs obtained by applying the proposed method is efficient and well suited for potential applications.**

Keywords - smart grid; communication; network selection; prioritization classification; dynamic attribute

I. INTRODUCTION

Smart grid is integrated with advanced sensing, communication and control. The two-way communication plays an important role in applications of energy production and consumers' homes and buildings, which could save energy, reduce cost and increase reliability [1].

Smart grid requires all the processes in the grid to be monitored and controlled in real-time. Researchers have paid more attention in smart grid communications. Wireless, optical and power line communication have been applied directly in smart grid. Wire communication technology such as power line communication has been studied in [2]. However, the use of power line communication has confronted several problems especially in applications with high signal attenuation and nearly electric interference. Wireless access networks can play a major role in automatic meter reading, remote system monitoring, and equipment fault diagnosing [3]. Moreover, wireless technology offers low installation costs and rapid connectivity, especially for areas without preexisting communication infrastructure. For example, for the reason that wireless sensor network could construct a highly reliable network with reacting to events with appropriate actions, it forms an essential communication technology in smart grid [4]. For improving the bit error rate, a frequently hopping wireless communication system is proposed in [5]. In [6], the smart grid wireless networks are modeled and communication delay is analyzed, which has characterized the minimal communication delay.

Basically, some types of information flows exist in smart grid. The flows contain heterogeneous traffic such as control commands, multimedia sensing data, and readings that need priority-based traffic scheduling schemes due to their quality-of-service requirements [7-8]. So a cognitive-radio-based smart grid has been introduced and spectrum allocation scheme has been proposed in [9-10]. In addition, GSM is the most popular cellular network, which has made it a strong competition in smart grid applications [11]. In [12], 4G/LTE technology and its usage infrastructure are investigated in detail, which provides mobile and broadband IP based communication. However, it is clear that the network performance degrades at peak hours.

For many smart grid applications, they have requirements with high reliability and low latency. For other applications, they have busty traffic and moderate latency, which requires bandwidth. Considering the large volumes of simultaneous messages, the messages would become bandwidth demanding, delay demanding and preference demanding, especially for the radio resource. A key element to realize smart grid is the deployment of an efficient and reliable information network [13]. Moreover, the mobile terminals in smart grid evolve towards a multimode architecture, which allows users to benefit from optimal network. In this paper, a heterogeneous wireless network transmitting smart grid traffic is considered.

The rest of the paper is organized as follows. Smart grid scenario and its communication infrastructure are described in Section 2. Section 3 describes network selection algorithm considered. Numerical results are provided in Section 4 and Section 5 concludes the paper.

II. SMART GRID AND ITS COMMUNICATION NETWORKS

Smart grid is an electricity network, which integrates all users' actions to deliver electricity supplies efficiently. The smart grid has the following key elements and issues, which is different from the traditional grid.

Distributed and stochastic production: the diffusion of renewable energy may shift the energy production from a scenario with small number of large production sites to a large number of small production sites spread over the territory. So different parts of the grid are not fed with the same energy at the same time, and consumption profiles or time zones contribute to unbalance the energy grid.

Energy market: in traditional energy grid there is a rigid individual seller to individual consumer market model, such as wind power and solar power may generate an energy market. In the market, the producer and consumer could trade energy, which may have a good help in smoothing fluctuations.

Load stress: stochastic and distributed production often correlate to price-based consumption in space. The availability of energy makes the grid more sensible to local overload.

Hierarchical communication in smart grid is required in above scenario over large geographical areas. In-home appliances are accessed in home area network (HAN). The HANs are connects by neighborhood area network (NAN) to the power distribution center. Power generation center, transmission center and control center connects distribution centers in wide area network (WAN).

In the future, NAN is a heterogeneous environment where multiple communication networks coexist. As one of the core technologies, communication network plays an important role in realization of all goals of smart grid NAN [14-16]. Communication network is required to transmit information of electronic devices and other power devices, which forms a real-time bidirectional information transmission in NANs. Furthermore, smart grid communication networks require higher availability and lower latency, which is different from those of other networks. For multipath, fading and noise, the coverage area of wireless network may be limited and some devices may be under poor coverage area. It is required to deploy denser base stations and more low cost relays. However, it is cost prohibitive and may increase interferences. Communication network is considered to be heterogeneous to ensure the characteristic features of reliability, self-healing, and scalability of smart grid. The applications running on communication networks are also heterogeneous for quality of service requirement. For example, Advanced Metering Infrastructure requires low throughput and can tolerate high latency, where alarm data requires high throughput and low latency.

In this paper, the use of a heterogeneous wireless network composed of several radio access technologies is proposed to manage smart grid traffic in NAN. And the properties of the heterogeneous NAN are:

1) Various delay and reliability are required for different users;
2) Various bandwidths are used for different users.

III. NETWORK SELECTION ALGORITHM FOR HETEROGENEOUS COMMUNICATION NETWORK IN SMART GRID

In smart grid, for delivery power from generating units to users, reliable real time information transmission is challenging due to low latency and high reliability. As a solution, for multiple communication networks environment, an adaptive network selection algorithm based on data prioritization classification is proposed.

A. Data Prioritization Classification

In smart grid scenario, in order to transmit mountains of data effectively, mechanisms for communication network selection should be planned and designed. Essentially, smart grid data should be categorized so that these data could be treated appropriately. The data classification is based on assuring that information is transferred securely and effectively. Data categories consist of control data, protection data, and monitoring data as well as other relevant categories. IEEE STD 2030TM-2011 provides guidance on classification range [17]. For example, data are treated to be critical based on the occurrences of abrupt emergency, disaster. So the data are handled differently in terms of classification.

The transfer time is a most important characteristic for smart grid communication, which has a relationship on delay caused by information technology and communication system. The delay can be described as $D = D_a + D_p$. For the propagation delay D_p, it can be reduced by prioritization classification. In smart grid, high priority relates to control and safety issues. Failure to meet high-priority criteria has the potential to result in loss of life, injury, and damage to assets. Medium-priority classification is for information exchange where there is a potential for damage to assets but not loss of life or injury. The low-priority classification is for information data exchange where there is no potential for damage to assets or risk to personal. For example, the delay weight is increased for high priority data, so the network with low delay could be selected. For the access delay D_a, it is $D_a = T_{re} + T_{res}$, T_{re} and T_{res} are the remaining time for the current transmission and system response time, respectively.

When there is new data access, it should wait the current data transmitted, which may result in latency time. As a solution, a data buffer is applied based on data prioritization classification. When access response is received, the prioritization is compared with the data being transferred. If the prioritization of the new data is higher, the data being transferred could be put into buffer, and the new data access is responded. When the new data has been transferred, it reads data from the buffer and responds the data with low prioritization. The data transferred in smart grid are classified into five grades described by values 1 to 5. The values 5 and 1 mean the highest and lowest prioritization, respectively.

B. Adaptive TOPSIS (A-TOPSIS)

In the network selection approach proposed in this paper, a better service and the reliability for the users are made. In making such decisions, the current user's preferences and the application that the user is intending to access are considered. On the other hand, it is important to ensure the data transmission and eliminate the unnecessary handover. In our proposed algorithm a pre-decision adaptive scheme is deployed.

Before handoff decision, the user determines whether the connections should continue using the existing selected network or be switched to another network to reduce the number of superfluous handoffs significantly. To this end, pre-decision scheme is proposed. When access request is received, network parameters are compared with the threshold value of access application. If the current network does not meet the conditions, network selection is implemented.

Communication quality shows characteristics state changing in time. TOPSIS considers all the alternatives, i.e., all the available networks, defined by the values assumed by the considered attributes. The procedure can be categorized in five steps. The proposed algorithm is a modification of the well-known TOPSIS.

In conventional network selection algorithm TOPSIS, the network attributes are considered constant, which could not reflect uncertain information and network condition.

The user preference (user profile) at the generic step is $P_i(t)$ in the i th alternative. The adaptive factor is Δt. Supporting the network performed, defining the i th alternative as

$$P_i(t)=\begin{cases} P_i(t-1)+\Delta t, \textit{transmission successed} \\ P_i(t-1)-\Delta t, \textit{transmission failed} \end{cases} \tag{1}$$

The attribute $P_i(t)$ is adaptive according to the access network. If access and transmission is performed successfully, the user preference is $P_i(t-1)+\Delta t$. Otherwise, when access and transmission failed, the user preference is $P_i(t-1)-\Delta t$. The new formulation of adaptive TOPSIS is proposed here for dynamic attributes.

1) Construct of the decision matrix

The decision matrix is expressed as

$$\boldsymbol{D}=\begin{bmatrix} s_{11} & \cdots & s_{1j} & \cdots & p_{1n} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ s_{i1} & \cdots & s_{ij} & \cdots & p_{in} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ s_{m1} & \cdots & s_{mj} & \cdots & p_{mn} \end{bmatrix} \tag{2}$$

where n and m are the number of attributes and alternative networks, and $\boldsymbol{D}_i(t)=\left[\boldsymbol{s}_i(t-1) \quad \boldsymbol{p}_i(t)\right]$. The attribute $\boldsymbol{s}_i(t-1)$ are static, such as bandwidth, transmission rate. The attribute $\boldsymbol{p}_i(t)$ is user preference, which is dynamic.

2) Building the weighted normalized decision matrix

The attributes should be normalized to remove the influence of dimension calculation of the normalized attribute values is as follow,

$$V_{ij}=\begin{cases} W_j \dfrac{s_{ij}}{\sqrt{\sum_{i=1}^{m} s_{ij}^2}}, \ i=1,2,\cdots,m, \ j=1,\cdots,n-1 \\ W_j \dfrac{p_{ij}}{\sqrt{\sum_{i=1}^{m} p_{ij}^2}}, \ i=1,2,m, \ j=1,\cdots,n \end{cases} \tag{3}$$

$$\boldsymbol{V}=\begin{bmatrix} v_{11} & \cdots & v_{1j} & v_{1n} \\ \vdots & & & \\ v_{(m-1)1} & \cdots & v_{(m-1)j} & v_{(m-1)m} \\ v_{m1} & \cdots & v_{mj} & v_{mn} \end{bmatrix} \tag{4}$$

where W_j is the weigh associated to the j th attribute, which must be selected by respecting the condition $\sum_{j=1}^{n} W_j = 1$.

3) Determining the positive ideal solution A^+ and negative solution A^-

$$\boldsymbol{A}^+=\left[V_1^+, \ \cdots, \ V_m^+\right]=\begin{bmatrix} \boldsymbol{s}^+(t) \\ p^+(t) \end{bmatrix}$$

$$\boldsymbol{A}^-=\left[V_1^-, \ \cdots, \ V_m^-\right]=\begin{bmatrix} \boldsymbol{s}^-(t) \\ p^-(t) \end{bmatrix} \tag{5}$$

And it can be obtained

$$\begin{aligned} \boldsymbol{s}^+(t) &= \left[s_1^+(t), \ \cdots, \ s_{n-1}^+(t)\right] \\ &= \left[\max_i s_{ij}(t), \ \min_i s_{ij}(t)\right], j=1,\cdots,n-1 \\ p^+(t) &= \left[\max_i p_{ij}(t), \ \min_i p_{ij}(t)\right], j=n \end{aligned} \tag{6}$$

and

$$s^{-}(t)=\left[\min_i s_{ij}(t),\quad \max_i s_{ij}(t)\right],\ j=1,\cdots,n-1$$

$$p^{-}(t)=\left[\min_i p_{ij}(t),\quad \max_i p_{ij}(t)\right],\ j=n \tag{7}$$

4) Calculation of the similarity distance

$$S_{ij}^{+}(t)=\left|s_{ij}(t)-s_j^{+}(t)\right|,\ i=1,\cdots,m;\ j=1,\cdots,n-1$$

$$P_{ij}^{+}(t)=\left|p_{ij}(t)-p_j^{+}(t)\right|,\ i=1,\cdots,m;\ j=n \tag{8}$$

$$S_{ij}^{-}(t)=\left|s_{ij}(t)-s_j^{-}(t)\right|,\ i=1,\cdots,m;\ j=1,\cdots,n-1$$

$$P_{ij}^{-}(t)=\left|p_{ij}(t)-p_j^{-}(t)\right|,\ i=1,\cdots,m;\ j=n$$

5) Calculation of relative closeness to the ideal network

This step includes calculating the relative closeness to the ideal solution, which is defined as

$$C_i(t)=\frac{\sqrt{\sum_{j=1}^{n-1}\left(S_{ij}^{-}(t)\right)^2+\left(P_{ij}^{-}(t)\right)^2|\,j=n}}{\sqrt{\sum_{j=1}^{n-1}\left(S_{ij}^{-}(t)\right)^2+\left(P_{ij}^{-}(t)\right)^2|\,j=n}+\sqrt{\sum_{j=1}^{n-1}\left(S_{ij}^{+}(t)\right)^2+\left(P_{ij}^{+}(t)\right)^2|\,j=n}}$$

$$i=1,\cdots,m \tag{9}$$

A set of alternatives can be ranked according to the decreasing order of $C_i(t)$. And the maximum is the ideal maximum.

The flow chart for the proposed algorithm is shown in Figure 1. The network that provides the highest rank value is selected as the best network to handoff from the current access network according to network conditions, service and application requirements, cost of service and user preference.

IV. SIMULATION RESULTS

Numeral results show good performance improvement of our proposed scheme over conventional handoff decision algorithm TOPSIS. In the simulation, the various parameters for network selection procedure of the best accessible network are as follows in Table 1.

The scenario considered contains three partly overlapping networks. During the simulation, Table 2 presents a snapshot of attribute values for these networks at the time of network selection.

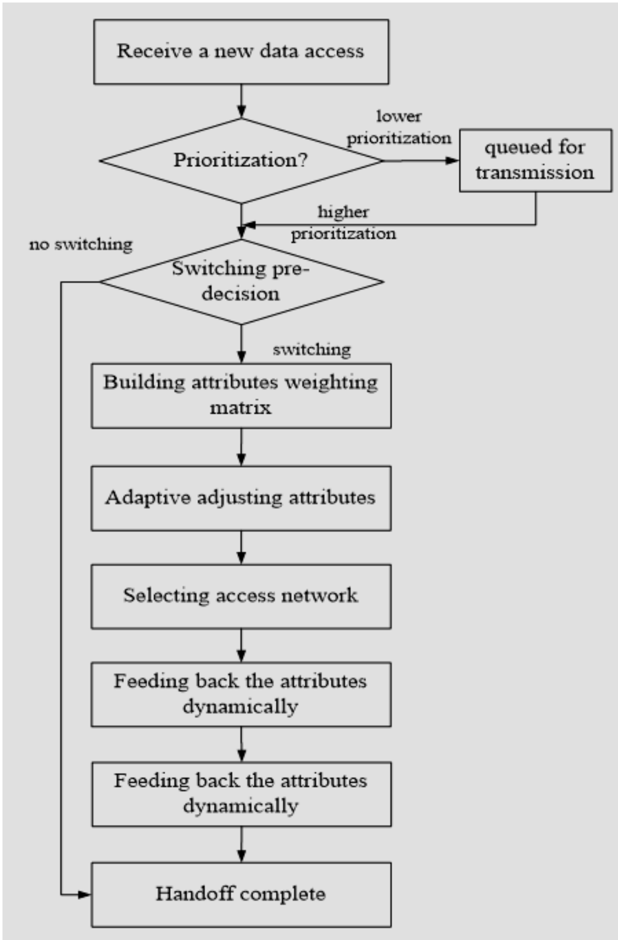

Figure 1. The flow chart for proposed adaptive TOPSIS

TABLE 1. THE ATTRİBUTE WEİGHTS OF DİFFERENT DATA TYPES

Data	Delay	Bandwidth	Safety	Reliability	Cost	Preference
Background data(B)	0.0498	0.0273	0.1004	0.1514	0.3472	0.3238
Control data(C)	0.1460	0.0239	0.4653	0.0728	0.0387	0.2533
Audio data(S)	0.4105	0.1289	0.0265	0.0455	0.0822	0.3063
Video data(V)	0.4400	0.2454	0.0221	0.0366	0.1309	0.0689
Alarm data(A)	0.4574	0.0235	0.2632	0.1406	0.0412	0.0740

TABLE2. ATTRİBUTE VALUE FOR THE CANDİDATE NETWORKS

Candidate Network	Delay	Bandwidth	Safety	Reliability	Cost	Preference
Network 1	700	11	2	3	0.5	5
Network 2	150	2	7	6	0.1	5
Network 3	50	0.8	5	7	0.4	5

In this simulation, five kinds of data are transferred randomly. The data with different prioritizations are accessed 500 times. The average delays are showed in Figure 2. It is clear that the average delay is about 3.2 time units without prioritization. When data are classified, the average delay is lower for higher prioritization data. The average delay has been reduced to 0.7 time units. The proposed adaptive method performs better than conventional TOPSIS for the reason that it has data buffer. Prioritization-First has improved the transmission performance.

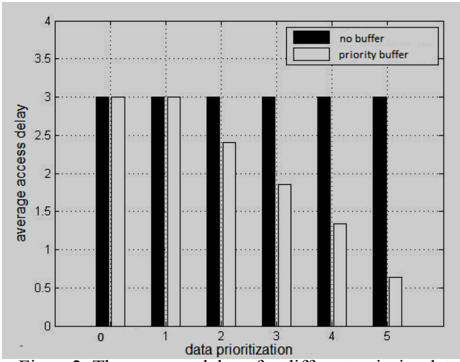

Figure2. The average delays for different priority data

Figure 3 shows that proposed adaptive method diminishes the number of handoffs with a value of 44%. We deduce that the proposed method provides better performances concerning the number of handoffs than conventional TOPSIS.

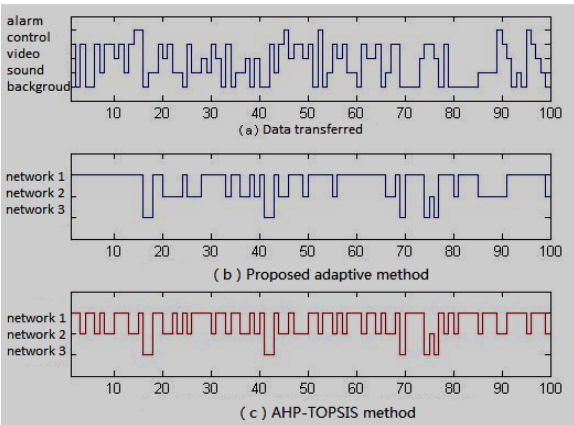

Figure 3. Average of number of handoffs

Figure 4 shows the number of handoffs for the two methods. From the simulation results, it can be seen that the proposed method has reduced the number of handoffs significantly, which could guarantee the smart grid data transmission.

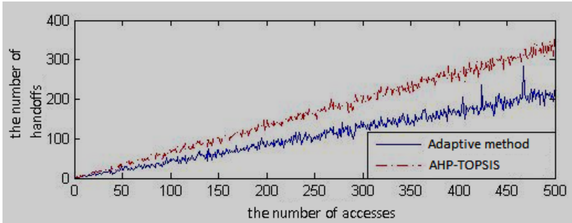

Figure4. The number of handoffs for proposed method.

V. CONCLUSIONS

With the evolution of communication devices towards a multimode architecture and the coexistence of multitude of wireless communication technologies, a smart grid is able to benefit simultaneously from the all of the above. The major issue in heterogeneous wireless communication is how to choose the most suitable access network considering low delay and high reliable for smart grids. To achieve this issue, an adaptive network selection algorithm is proposed to rank the available networks efficiently. It defines data priority and data buffer, which achieves the transmission timely and reliably. Moreover, the results show the dramatic advantage of the proposed method on the reduction of the number of handoffs. Our new method can deal with the limitations of conventional network selection method with ping-pong effect applied in smart grids.

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