ISSN 2616-5767 Vol.4, Issue 6: 55-60, DOI: 10.25236/AJETS.2021.040610

Adaptive Detection for Virtual MIMO System in Smart Home Environment

Qiyu Luo[1,a]*, Zihan Wang[2,b]

[1]*Chengdu University of Information Technology, Chengdu, Sichuan, China*
[2]*Changshu Institute of Technology, Changshu, Jiangsu, China*
[a]*596257472@qq.com*, [b]*869967499@qq.com*
**Corresponding author: 596257472@qq.com*
These authors contributed equally to this work

Abstract: *Smart home devices have received considerable attention recently due to the promise of a large number of applications. Researchers are stepping up research with the goal of creating a smarter, more convenient and more comfortable life. A wide range of smart home devices are being developed to improve signal reliability and stability. This paper comprehensively introduces the smart home and its application, MIMO system, and some methods of signal detection. On this basis, the main characteristics of K-Best detection method are introduced. At the end of this paper, we summarize the current smart home technology, and its development prospects are introduced in detail.*

Keywords: *Smart home, MIMO, Sphere detection*

1. Introduction

With the rapid development of the global economy and the arrival of the era of the Internet of Things [1, 2], the demand for intelligent services and high quality of life are increasing day by day, and the application of smart home has brought wide attention of global home appliance enterprises [3, 4].

At present, more and more people are willing to try intelligent devices at home. Thus, smart home market is also gradually expanding, which has attracted the entry of many enterprises. Based on consumer needs, a variety of ideas are constantly updated and proposed. The U-Home [5], for example, is designed by enabling information sharing between people, appliances, external networks and after-sale systems. As known, to guarantee the reliability of the transmitted signals among intelligent devices at home, multiple input multiple output (MIMO) [6] can be applied, because there is a virtual MIMO system in smart home.

MIMO system uses multiple antennas for the transmission and reception of the signal terminal. Under the premise of not increasing the transmission power, the transmission rate of the system is increased and the communication quality of users is improved [7]. The main feature of MIMO system is to turn multipath communication into a favorable factor for users, and make use of its inherent characteristics to improve user experience and satisfaction for smart home devices. Since the signals of multiple antennas are mixed together, how to effectively distinguish the signals i.e., signal detection is a particularly important technique [8, 9].

Signal detection means information processing and automatically detect the transmitted signal correctly, to improve the transmission quality among smart devices at home. Of course, different smart devices and different family have different requirements for smart experience at home. For instance, with precise remote control, we can achieve remote control of high-risk tasks without risking our lives. Low-delay and high-reliability communication can make our life more efficient, convenient, safe and intelligent, and can give us more intelligent experience. The optima MIMO detection is maximum likelihood (ML) detection. It reduces the spatio-temporal correlation between antennas, reduces the crosstalk between codes and improves the transmission rate of information. However, the computational complexity of the ML detection exponentially increases with the increasing number of antennas. In order to reduce the computational complexity and achieve the optimal detection performance, sphere detection algorithm was proposed [10]. Sphere detection optimizes the algorithm and reduces the computational complexity by constraining the searching range within a sphere with an initial radius. Considering the difference requirements of smart devices at home, a K-best sphere

ISSN 2616-5767 Vol.4, Issue 6: 55-60, DOI: 10.25236/AJETS.2021.040610

detection [11, 12] is proposed to apply in the signal detection of virtual MIMO system at smart home.

Due to the different situations of each user and smart device, different K values could be equipped to meet people's different needs for smart home systems. In general, the implementation of K-Best algorithm needs to sort the paths of each searching layer and select the smallest K nodes, thus reducing the search space and the computational complexity [13]. In the application of smart home, due to the increase of user demand, the search scope is also expanding. K-Best algorithm can obtain the optimized detection performance to meet the different needs, and implement adaptive detection by automatically setting the parameter K [14, 15].

This paper is organized as follows. Section II introduces smart home systems. MIMO system model is described in Section III. Besides, signal detection methods is demonstrated in detail in Section IV, and Analysis and Discussions are given in Section V. Finally, conclusions and future work are summarized.

2. Smart Home Systems

Smart home has a very wide range of applications in life, especially in residents' families. The top application scenarios are as follows:

Environmental automatic control, such as the control of family central air conditioning, indoor air quality monitoring and control.

Provide a full range of home entertainment, such as home theater system and home central background music system.

Modern kitchen and bathroom environment.

Family information service, that is, the ability of managing family information and contacting with community property management company.

Automatic maintenance function. The intelligent information home appliance can be downloaded automatically from the manufacturer's service website directly through the server, and the driver and diagnostic program can be updated to realize the intelligent fault diagnosis and the automatic expansion of new functions.

Safety prevention. Intelligent security system can monitor the occurrence of illegal break-in, fire, gas leak and emergency call in real time. Once the alarm situation occurs, the system will automatically send out alarm information to the center, and start the relevant electrical appliances to enter the emergency linkage state, so as to realize the active prevention.

Interactive intelligent control. The voice control function of intelligent home appliances can be achieved through the voice recognition technology; and smart home proactive action response is obtained through a variety of active sensors (such as temperature, sound, movement, etc.).

Figure 1. An example map for smart home systems

ISSN 2616-5767 Vol.4, Issue 6: 55-60, DOI: 10.25236/AJETS.2021.040610

In order to realize the aforementioned advantages, the smart home devices need to send and receive multiple signals by multiple antennas. Thus, this paper introduces the system which could improve network performance by using multiple antennas to suppress channel fading. When a radio signal is reflected, it creates multiple signals in space. The MIMO technology improves the transmission rate of information, as well as the reliability of the signal, and enhances the user's sense of use.

3. MIMO System

MIMO is a technology that can be used to improve the performance of the network. It exploits multiple antennas to suppress channel fading. When a radio signal is reflected, it will produce multiple signals. In the system model, each transmitting antenna sends different bit stream information, and each receiving antenna receives linear synthesis information from the transmitting antenna as shown in the figure below.

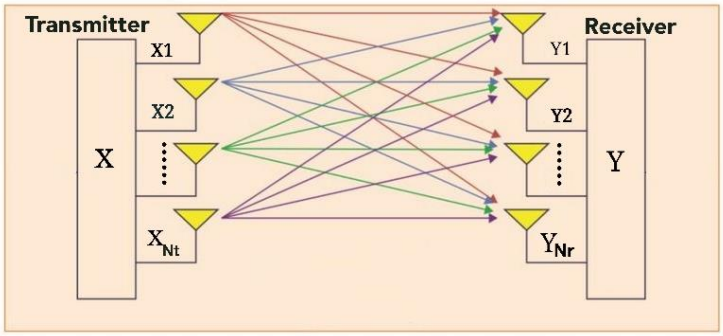

Figure 2. MIMO system model

According to the system model, the formula could be derived by

$$Y = \begin{bmatrix} h_{11} & \cdots & h_{Nt1} \\ \vdots & & \vdots \\ h_{Nr1} & \cdots & h_{NtNr} \end{bmatrix} * X + N \quad (1)$$

With the increase of the number of antennas used, the complexity of the implementation of MIMO technology will increase greatly, which limits the number of antennas used and fails to give full play to the advantages of MIMO technology. At present, how to reduce the algorithm complexity and implementation complexity of MIMO technology on the basis of ensuring certain system performance has become a huge challenge, especially for the signal detection techniques at the receiver.

4. Detection Algorithms

The signal detection algorithms of MIMO system include Zero forcing (ZF) algorithm, Minimum Mean Square Error (MMSE) algorithm, Maximum Likelihood (ML) algorithm, sphere detection (SD) algorithm, etc. With the increase of the number of antennas in the smart home system, the detection of large-scale integration is needed. Therefore, K-best algorithm is adopted in this paper, which is one of width-first algorithms, and is more appropriate than ML algorithm and the conventional SD algorithm. It can reduce the search space, has a fixed complexity, and is easy to implement.

In fact, K-best algorithm is a simplification of ML. To understand K-best, we must first understand ML algorithm.

ML algorithm

One characteristic of ML is that it calculates the partial Euclidean distance for each step of calculation, and selects the minimum Euclidean distance as an alternative for the next step of calculation. The receiver signal is derived by

$$Y = HX + n \quad (2)$$

Where $X = [X_1, X_2 \dots \dots X_{Nt}]^T$ is the transmitting symbol vector, and $Y = [Y_1, Y_2 \dots \dots Y_{Nr}]^T$ is the receiving symbol vector. H is the channel information matrix with $N_r \times N_t$ Dimension, where the element $h_{j,i}$ is the channel gain from the transmitting antenna $i(i = 1,2, \dots \dots, n_t)$ to the receiving

ISSN 2616-5767 Vol.4, Issue 6: 55-60, DOI: 10.25236/AJETS.2021.040610

antenna $j(j = 1,2, \ldots \ldots, n_{r)}$. $n = \left(n_1, n_2, \ldots \ldots n_{n_r}\right)^T$ is Gaussian noise, where each component is independent and distributed about $N(0,,\sigma^2)$.

The mathematical expressions for ML detection is given as

$$\hat{S}_{ML} = \arg_x \min_{X\in\Omega}(\|Y - HX\|^2) \quad (3)$$

Where X is the hard input vector, Y is the received vector, Ω is the set of all possible N_t dimensions transmitting signal constellation points. The performance of this algorithm is the optimal detection. The characteristic of this algorithm is that it needs to search all the constellation point set to get an optimal result. However, with the increase of the number of antennas and the modulation order, it brings great challenges to the computing resources. Therefore, we introduce the SD algorithm to solve this problem. SD algorithm generates a search tree by QR decomposition of the channel, and obtains the LLR (logarithmic likelihood ratio) that minimizes the two Euclidean distances based on the search of the tree.

SD algorithm

The principle of SD is that the detection space of all constellation points is limited to a sphere with a radius d centered on the initial signal estimated by the received signal. We set the conditional probability density of the received signal as:

$$P(Y|H,X) = \frac{1}{(\pi\sigma^2)^{N_t}} \exp\left(-\frac{1}{\sigma^2}\|Y - HX\|^2\right) \quad (4)$$

Then the maximum likelihood estimate of the transmitted signal X is

$$\hat{S} = \arg \max_{S\in\Omega^n} P(Y|H,X) = \arg \min_{S\in\Omega^n} \|Y - HX\|^2 \quad (5)$$

Where Ω is the set of constellation points, QR decomposition is performed on the channel, H=QR, where Q is the unitary matrix, and R is the upper triangular matrix, which is obtained:

$$\|Y - HX\|^2 = \left\|QQ^H(Y - HX) + \left(I_{n_g} - QQ^H\right)(Y - HX)\right\|$$

$$= \|QQ^H(Y - HX)\| + \left\|\left(I_{n_g} - QQ^H\right)(Y - HX)\right\| \quad (6)$$

If $Y' = Q^H Y$, So $\hat{S} = \arg \min_{S\in\Omega^n} \|Y - HX\|^2$ is equivalent to $\hat{S} = \arg \min_{S\in\Omega^n} \|Y' - RX\|^2$. So in order to search for the optimal solution, a search tree is constructed. The first layer has m nodes. Different nodes have different values, which are determined by the function $(f_{n_T}(X_{n_T})(x \in \Omega))$. The second layer is generated m^2 nodes by m nodes of the first layer; finally, layer n generates m^n nodes. The path with the smallest accumulated cost in the leaf layer is the optimal solution.

The difference between SD algorithm and ML algorithm lies in that SD searches in a predetermined finite sphere area, and the calculation is reduced by limiting or reducing the search radius. However, in the low SNR area, the algorithm complexity is still very high, which is close to ML algorithm, so we will introduce K-Best algorithm to improve it.

K-best algorithm

In contrast to the deep search of SD algorithm, K-Best algorithm uses breadth first search method. The depth-first algorithm performs both forward and reverse searches, while the breadth-first algorithm only searches in the positive direction, but ensures the best candidate at each level. Regarding the K-best algorithm, after QR decomposition of the channel, set $Z=QH_y$, then

$$\hat{S} = \arg \min_{S\in\Omega^n} \|Z - RX\|^2 \quad (7)$$

Ω satisfies all the points in $\|Z - RX\|^2 \le d^2$, $\|Z - RX\|^2$ is the total cost measure of signal X, which involves the sum of m terms. So there's an m-level tree that can represent the search problem, and it's going to be a set of leaves. The next step is to initialize a path with a measure of 0, enter the loop after the signal is input, expand from each previously retained survivor path to the competitor path, and update the cumulative metric of each path to select the optimal path based on the cumulative size of the competitor path, and discard the remaining paths. If the iteration has reached the end, the algorithm is stopped, otherwise the loop continues and its algorithm flow diagram is shown below.

ISSN 2616-5767 Vol.4, Issue 6: 55-60, DOI: 10.25236/AJETS.2021.040610

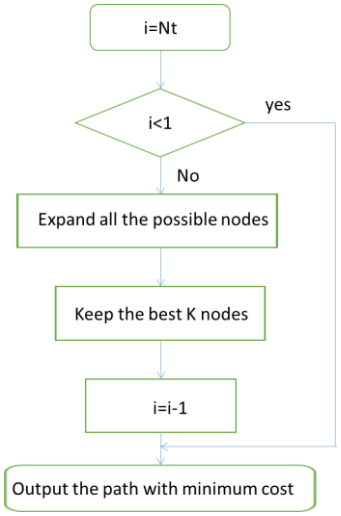

Figure 3. The diagram of the proposed adaptive detection algorithm.

5. Analysis and Discussions

In smart home scenario, a variety of devices are connected to the internet, which consists a virtual MIMO situation. Therefore, a proper detection method is needed to achieve better performance and affordable complexity to guarantee the quality of signal transmission among smart home. Therefore, in this paper, an adaptive detection method is proposed by using K-best SD in virtual MIMO system of smart home. K-best SD searches the tree layer by layer and keeps only the best K candidates at each layer. This SD sorts all the child nodes based on their partial costs and selects the K best paths. Finally, when the bottom layer is reached, the leaf node with the minimum cost is selected as the solution.

Thus, the search running time of the K-best algorithm is fixed and depends only on K and the number of layers in the tree. The K-best SD search procedure is briefly described as follows:

1) Initialize the partial cost to be 0 at the root of the search tree;

2) Expand all the nodes at the current layer and compute the partial costs for all these potential successors;

3) Sort these nodes in the ascending order of their costs, and retain the best K nodes with the smallest costs;

4) Prune all other nodes and update the partial cost for each candidate;

5) Check if the bottom layer is reached; if yes, then the leaf node with the smallest cost is the estimate; or if no, reduce the layer number, and go to 2).

The K-best SD are hardware-friendly because they have predetermined visited node and constant throughput. Therefore, for the scenario of smart home, it is adaptive for the users to choosing difference K for different needs of smart devices.

6. Conclusions and Future Works

This paper introduced the present situation of smart home and its extensive application prospect. The purpose of this paper is to analyze the development trend of current intelligent devices, introduce the application of virtual MIMO system, and the related signal detection methods. Finally, the future development trend of smart home is expounded.

With the development of modern hardware equipment and software technology, low delay and high reliability signal detection method can improve the communication transmission rate. In this way, we can improve the comfort and happiness of our life, which can give us more intelligent experience. In the future, when hardware devices and the Internet develop to a certain extent, we will master more optimized signal detection methods. It not only optimizes the algorithm to a greater extent, but also reduces the computational complexity. Due to the different situations of each user and smart device, an adaptive detection method with different K values can be equipped to meet people's different needs for

ISSN 2616-5767 Vol.4, Issue 6: 55-60, DOI: 10.25236/AJETS.2021.040610

smart home systems. In the application of smart home, due to the increase of user demand, the search scope is also expanding. The proposed adaptive detection method can obtain optimized detection performance to meet different requirements, and realize adaptive detection by automatically setting parameter K.

With the development and popularity of various home smart sensors, mobile remote control is not the real intelligence. With the help of big data and intelligent algorithms, all the equipment automatically operates, and more deeply join into the life while people cannot feel its existence. In future, we would focus on how to achieve real intelligence through automatic modeling processing of data, combined with intelligent voice technology and AI technology.

References

[1] Liang Mingyuan, Chen Qiang, Zhang Chongqi, et al. Design and implementation of intelligent home system based on Raspberry Pi. Sensor and Microsystem, 2021, 40(2): 105-107,112.
[2] Wang Rong, Chen Hongjun. Design of Smart Home System Based on Modularization [J]. Computer Knowledge and Technology, 2021, 17 (1):205-207.
[3] Jiang Wenjie, Nie Panhong, Zhang Zhan. Intelligent Home Interaction System Based on Intelligent Cloud Control [J]. Computer Knowledge and Technology, 2021, Vol. 17 (2):45-47, 64.
[4] You Hanting. Application and Influence of Smart Home in Interior Design [J]. Footwear Technology & Design, 2021, (3):25-27.
[5] ZHANG Liangkai. Haier U-Home: Smart Home Leader [J]. Urban Development,2017,(18).
[6] Pan Xuewen, Shao Jinxia. Simulation of MIMO system based on MATLAB [J]. Popular Science and Technology, 2020, 22 (8):5-7, 11.
[7] DAI L, WANG Z. Spectrally efficient time—frequencytraining OFDM for MIMO systems[J]. IEEE Journal on Selected Areas in Communications, 2013, 31(2):251—263.
[8] Zhu Fusheng, Lu Zhaohua, Hu Liujun. Research on 5G Multi-antenna Technology [J]. Shanghai Information Technology, 2017, (5):68-72.
[9] XU Sha-jia. Application of Multi-antenna Technology in Cellular IoT [J]. Electronic Technology and Software Engineering, 2019, (8):51.
[10] Xie Zhibin, Zou Weichen, Xue Tongsi. A Low Complexity Spherical Detection Algorithm for MIMO System [J]. Ship Science and Technology, 2013, 35(008):28-33.
[11] Yang Jialin, Tong Yi. An Improved K-Best Algorithm for Signal Detection Based on MIMO [J]. Modern Navigation, 2017, Vol. 8 (2):142-146.
[12] Hu Niankun, Peng Daqin. A Low Complexity K-Best Detection Algorithm for MIMO System [J]. Guangdong Communications Technology,2014,(3).
[13] Zhou Qian, Lou Xizhong, Chen Yanmin. Low complexity K-Best detection algorithm for bit sorting [J]. Journal of China Jiliang University, 2013(03):248-254.
[14] LIU Fei, LI Haitao. Design of Low Complexity K-Best MIMO Detector [J]. Journal of Circuits and Systems,2011, (No. 6).
[15] LIN Yun, WANG Yu. Research on K-Best Spherical Decoding Algorithm in MIMO System [J]. Journal of Radio Science,2009, (No. 1).