Power Consumption in Automated Service-Oriented Buildings using Fuzzy KNX Protocol

Sreejith Damodaran, S. Bhavani, K.Muthukumar

Abstract: ***Automating a building is considered to be a complex task with the availability of a large number of devices like home appliances, sensors etc. In addition to this, continuous monitoring of these devices requires extensive computing devices that route the devices with a needed protocol. Proper selection of a particular device that consumes more energy during an ideal time is an intelligent task. To efficiently conserve the energy in a building and to effectively monitor the activity of the device constantly, a novel architecture is proposed at network layer. This architecture makes use of KNX protocol that helps in routing the devices effectively from a monitoring station. In addition to this, to improve the monitoring and controlling activity from a main server fuzzy devices have been added with KNX protocol. Fuzzy KNX protocol is applied over both non-residential and residential buildings through this automated communication protocol. The devices are connected and interlinked with each other through two way bus or a full duplex channel that allows both controlling and monitoring at the same time. The feedback signals from the surrounding sensors for a particular appliance in a room environment is fed into fuzzy that helps in controlling the appliance through the control devices. This behavior has been divided into two modules: the first module has the control over each rooms and the second module controls each floor. Using this proposed model, reducing the consumption of electrical energy from unusual electrical appliances that are kept ON ideally is tried. The system is tested in building automation software that helps suitably in implementing the proposed model. Also from the results obtained it could be found that the Fuzzy KNX model works well in automating a building using a full duplex channel. Finally, this system helps in reducing the energy consumption in buildings derived from the simulated prototype.***

Keywords: ***Energy consumption, Fuzzy KNX automation, full duplex system, Monitoring and Controlling***

I. INTRODUCTION

In recent years, advancement in communication technology increased the possibility to improve the automated environment in buildings. This increases the comfort, security and reduced energy consumption that aims at reducing the fuel cost in environmental aspect [1,2]. The device needs to interact and communicate automatically without the user intervention.

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The decisions should be taken based on multiple factors that include the preference and presence of user in a particular environment. Intelligent systems ought to act as a supervisory system [2] that helps in controlling and monitoring the whole environment without user interaction. Presently available standards for home automation provide an uncomfortable signaling for flexibility [3] and autonomous operation, faster such that these standards have to be improved with better automaticity without user intervention and should be made flexible to work in static environments. In order to improve the intelligence of these standards, a dynamic mansaging authority or a dynamic centralized server needs to be designed to achieve better control and adoption over static location. To achieve such intelligence in a standard, dynamic management over the control information or signals in a building scenario with additional soft computing intelligence is needed. Thus a building automation standard along with soft computing intelligence could manage well the control and monitoring over a smart building without human intervention.

In a smart building environment, the main components equipped with the protocol standards are actuators and sensors. This supports the automation process with its distinctive function such as setting, switching, measuring, [3] monitoring and controlling [4]. The control signals from these components will be sent to the central server that in turn helps mainly in monitoring and controlling the building environment. At present, building automation system has controllers that serve only with ON or OFF functions that is highly unreliable in case of humidity control, temperature level of a room, air quality and natural light availability [5]. The main drawback behind these controllers is that, it will not take into account the actions happening in the real room environment. In order to control all the appliances in a room environment, soft computing approach with better rule selection could efficiently manage the devices. Soft computing with rule selection can help in controlling the real time happenings in room environment. Thus for better rule selection, this research has approaches fuzzy system integrated over a standard building automation protocol. In this research, KNX protocol is been considered as a protocol standard for building automation system. The interfacing of fuzzy with KNX protocol is made with full duplex lines connected across all the sensors and centralized main server. Here, the controlling and monitoring operations are carried out in centralized main server at both physical layer and network layer level. The main aim is to reduce the energy consumption that in turn saves the resource and money.

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Thus to achieve this objective, this paper evaluates the effectiveness of fuzzy over KNX standard with full duplex lines in a building automation system.

The remaining of this paper is organized as follows. Section 2 reports the relating articles based on fuzzy and KNX standard for building automation. Section 3 clearly depicts the model proposed to for energy consumption in an automated building environment. Section 4 evaluates the effectiveness of fuzzy based rule selection over KNX standards and its capability over building automation environment. Finally, section 5 reports the conclusions for this research work.

II. RELATED WORKS

In the follows, the main literatures related to fuzzy and KNX standard over building automation system have been reported.

KNX standard in building automation

To reduce the interaction between the operational scenario and the user, an automated environment is needed that should be flexible to manage the appliances automatically. [6] Described the best use of KNX protocol in relation with other commercial building automation protocols such as ALEX, NL Facilities, Lon Maker etc. The main issues associated with these protocols are the interoperability and selection of proper device. KNX offers better solutions for these issues and reduces the time consumption in monitoring and controlling operations. Michele Ruta et al. (2011) [2] proposed semantic based backward compatible KNX standard using semantic annotation between the user and device functionality. This approach helps in attaining decision support through the semantic annotation approach in KNX standard. Although this method proved to be effective, it has its own drawback because of the user interaction with device. This in certain time cannot provide a better interaction between the user and device. Thus the elimination of user can provide a more appropriate reasoning to improve the profile of the research. Wolfgang Kastner and Stefan Szucsich, (2011) [7] proved the effectiveness of KNX standard compared with other building automation protocols. Using extensible Markup Language (XML), the encoding is done to provide a reliable communication between the devices. I -V Sita, Petru Dobra, (2014) [8] proposed a solution without semantics and this system uses the interaction of user sensed by the sensors for automatically controlling the building. This is done mainly to avoid the security leaks in routing servers using KNX standard. Faster integration of KNX standard towards building management proved the effectiveness of this protocol compared with other building automation standard [9]. From this it is concluded that there is effectiveness of KNX standard over building automation system.

Fuzzy technique in building automation

The effectiveness of KNX standard, apart from security breach could also be used for reducing the power consumption in buildings. To do this, use of certain rule based systems is needed in the building environment that should suit the best for real time happenings within a building environment. It is found from [6] that effective utilization of optimization algorithms over KNX building automation standard. Sohair F. Rezeka et al. (2013) used a strategy with fuzzy based approach that classified the rooms into three categories based upon the user utilization for a particular room. This fuzzy based automation in buildings helped in reducing the error rate for both humidity and temperature systems within acceptable limits. Also this method provides optimal performance in building automation when compared with normal operations. When the fuzzy based system is compared with a normal controller, it proved to be effective in terms of controlling and monitoring the appliance [10]. This upgradation with fuzzy over buildings helps in reducing the negative impact on environment than with normal controller [4].Yazeed Yasin Ghadi et al. (2014) used fuzzy system to control lighting and air quality for creating a comforting environment within a building. This fuzzy logic based controller helps in reducing the energy consumption in buildings based on numbers of occupants in a particular room environment. Chirag Deb et al. (2015) [11] used two selection criteria that used Neural Network and Neuro Fuzzy learning system through training and testing patterns. This study concentrated mainly on forecasting model to reduce energy consumption through these learning systems. The rule is divided into five classes based on the inputs over three buildings to calculate each day’s power consumption. The energy readings are calculated from the meter readings taken from the three buildings and finally the results gave a better prediction accuracy based on regression value obtained for both training and testing case.

III. MATERIALS AND METHOD

Building automation system could be well implemented over an Information Technology (IT) office environment. Here the usage of electrical appliances might be high when compared with other relative buildings. Also, the wastage of power during unavailability of users or the employees might be treated to be more. This problem has been increasing daily since the IT infrastructure is growing each day. Thus to avoid such problems, a building automation model using fuzzy based KNX protocol standard is proposed.

Firstly, the improvements could be made by categorizing a building based on the availability of users and usability of appliances in each floors. Since there will be a number of rooms in each floor, the rules there narrowed down further based on the availability of rooms in a particular floor. Thus, total selection of rooms in a floor could be used for defining rule selection strategy in simplified fuzzy logic design. This design comprises rules based on three categories: total number of floors, total number of rooms and total appliance in each room. Also in terms of each room, there are five categories that include: very important rooms (work station), important rooms (office rooms), normal rooms (front office), less important room (meeting room) and finally least important rooms (miscellaneous rooms like rest room and cafeteria).

Secondly, defining rule based on the first category depending on the number of available users and usability of devices in a particular room. Further depending on the room category, the rule is defined. This fuzzy device is installed for each floor in a centralized room server along with KNX standard that uses full duplex line for monitoring and control.

KNX Protocol

The main flexibility associated with KNX protocol is that its functionality can be expanded and changed each time. Former KNX system uses a two wire bus in parallel with 230V supply line but in our proposed system to reduce the complexity in installation we are going with full duplex bus in parallel with electrical supply. This 230V supply line helps in connecting all the components associated with KNX and the household appliances. The full duplex lines helps in transmitting the control signals that helps in transmitting faster the signals without any interference. This could help in increasing the flexibility of KNX over buildings, since the use of separate line over each component and appliance reduces the flexibility. The main components associated with KNX standard is power supply units, couplers and interfaces. The first one generates voltage required for full duplex lines; second for connecting the bus segments and third one is used for connecting the programmed devices. Sensors and actuators play a major part in controlling and monitoring the building without the user intervention for switching ON or OFF the device. The former one gathers the information from the room and sends the control signal through full duplex line. This control signal includes the temperature of the room, air capacity, and lighting. The latter one receives the data from the centralized server that includes controlling air conditioning systems, heating and dimming lights.

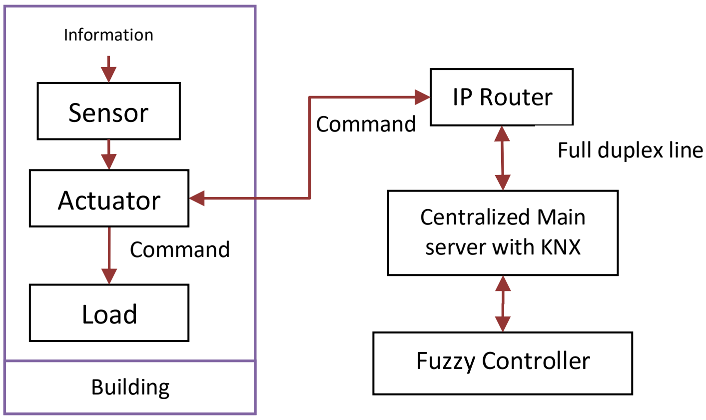

Fig. 1 Architecture of Fuzzy KNX Building Automation System

The main functionality associated with KNX protocol is that it can support lighting control, air conditioning, cooling, ventilation, shutter control, blind control and remote meter reading.

Two Way duplex line in KNX standard

The main purpose of using full duplex communication in KNX standard is to avoid collision when command signals are sent to the server through IP router. Also, subsequent delay could be avoided using this full duplex line in transmitting the command signals. This helps to improve the communication, as well it can improve the faster switching operation, thereby reducing the consumption of power. The architecture of which is shown in fig. 2.

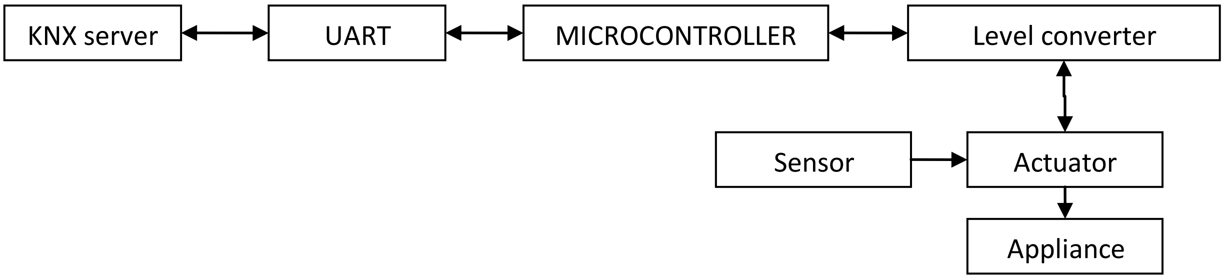

Fig. 2. Full Duplex communication in KNX

Full duplex communication requires the use of universal asynchronous transmitter receiver (UART) medium to connect itself with a microcontroller. A level convertor is used here to maintain the signal level between -/+5V for the proper supply of signals between actuator and the level converter. Here soon after the sensor sends feedback to actuator, the communication is made to the host controller at the server through the use of full duplex lines. The main problem associated with KNX communication is that the host controller can detect the end of packet (EOP) timeout only after 2 to 2.5 ms i.e. EOP can be detected by host controller by supervising the gap in EOP that has the time delay between 2 to 2.5 ms.

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This EOP signal is needed explicitly to drive the frames in the DataStream for communication between the source appliance and host controller. The use of full duplex with UART and microcontroller helps in reducing the gap between the received frames. To avoid such a problem, a filler signal could be added in this gap such that exceeding threshold problems could be avoided. Here the filler signal or frame gap is inserted into the character stream using escape sequences. This frame gap operated at 19.2 bps generated by the microcontroller unit helps in avoiding the shorter accommodation of holding the signal before the execution of EOP signal. Thus full duplex communication is made suitable for KNX communication without additional signal line with maximum compatibility.

Fuzzy Server Interface

Soon after operating at the physical layer, the next operation to be performed is at network layer using Fuzzy interference method in centralized server. Fuzzy is made to optimize the signals that come from the actuator to the KNX input. The main use of KNX is to provide routing with minimum delay and fuzzy helps in optimizing the control signals to the appliances. The operation of fuzzy is based on the rules generated with respect to the conditions based on the room structure and the importance of room in that building. The rooms are categorized into five units and are defined in previous section Depending on the users availability and power consumption of devices, the rules are generated.

A dual fuzzy system (F1 and F2) is used in this operation, where first fuzzy device calculates the total availability of room in a building and total number of different room segments. The second fuzzy calculates the total number of users in each room, total appliances in each room and total power consumed by each device. Thus the fuzzy system connected with server calculates all these values and are taken as an input to the fuzzy system. With the generated input signal, it is possible to generate rules based on and/or operator. Thus membership function is calculated for each device that involves total rooms, total room segments in F1 and total appliances, power consumed and user availability in F2. The rules are generated based on the main objective i.e. to reduce the power consumption in each room and using it efficiently. The membership function with triangular shape is taken as input response for the dual fuzzy management. The very important room is termed as VIR, important rooms are termed as IR, normal rooms are termed as NR, less important room is termed as LIR and finally least important rooms are termed as MIR. Also total number of rooms is represented as TR; power consumed as TP, total appliances as TA and total user availability as TU. Secondly, defining rule based on first category depending on number of available users and usability of devices in particular room. Further depending on the room category, the rule is defined. This fuzzy device is installed for each floor in a centralized room server along with KNX standard that uses full duplex line for monitoring and control.

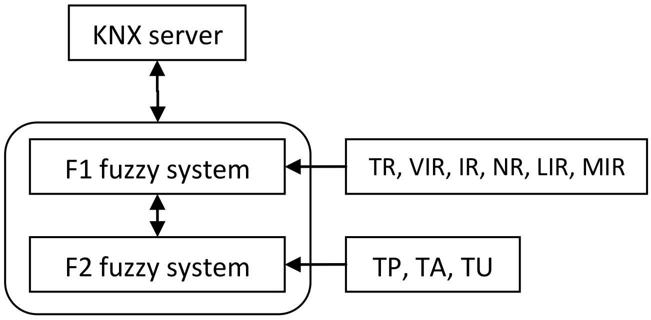

Fig. 3 Full Duplex communication in KNX

Fuzzy rule for F1 is categorized in the following diagrams: the rule for fuzzy F1 system is defined based on two categories. The first category involves the total room availability in each floor and the second membership function involves the important room segments i.e. TR in each floor and VIR, IR, NR, LIR and MIR. Fuzzy membership function is generated with 15 rooms in a floor shown in fig. 4. Here the availability of 15 rooms in a floor is generated using a membership function and this could increase or decrease based on the rooms availability in each floor. This could be narrowed down into important room segments like very important rooms (3 in that floor) shown in fig. 5. Similarly other rooms like IR, NIR, LIR are shown in fig. 6,7,8 and 9 respectively. This room availability is classified in fuzzy based on the TR value and soon after the classification of rooms; output from F1 is given as an input to F2 system.

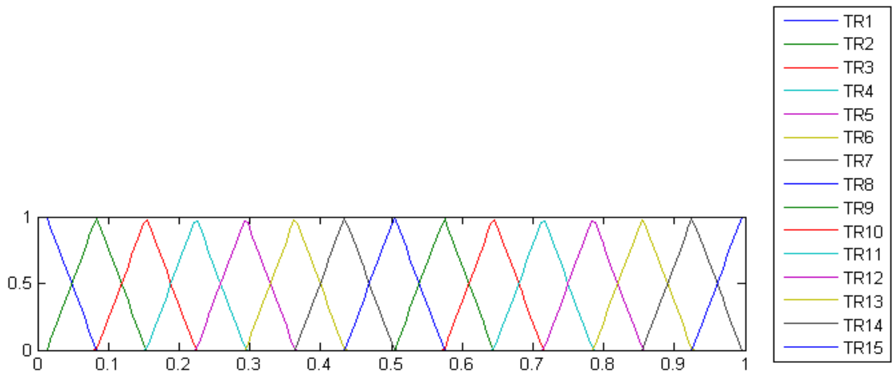

Fig. 4 Input membership function of TR in a Floor

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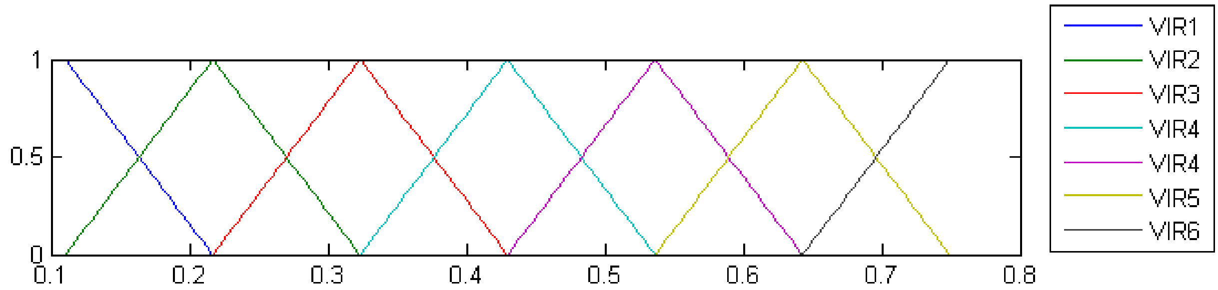

Fig. 5 Input membership function of VIR in a Floor

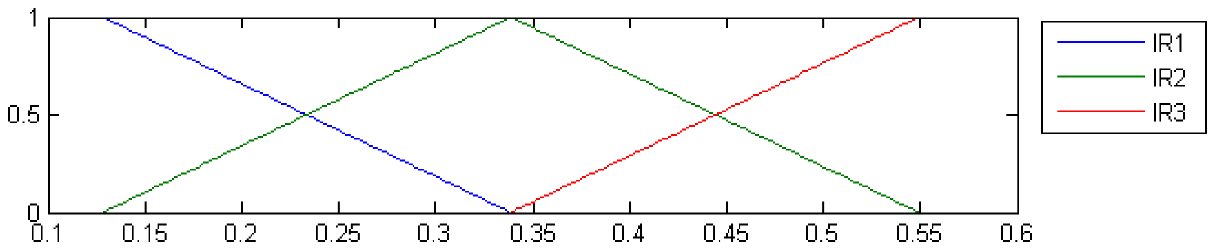

Fig. 6 Input membership function of IR in a Floor

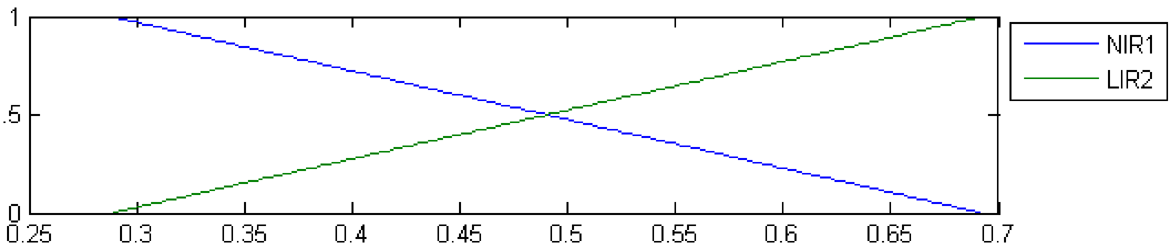

Fig. 7 Input membership function of NIR in a Floor

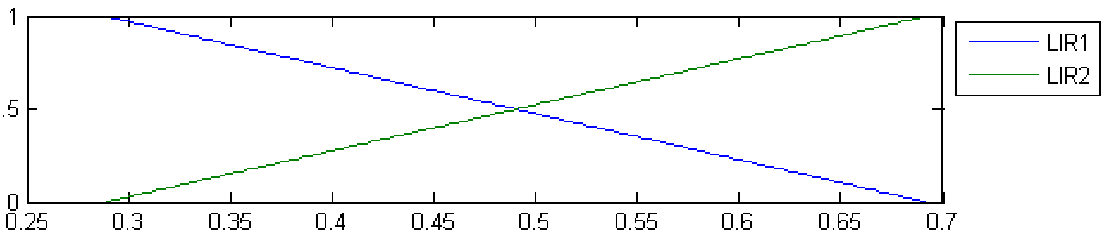

Fig. 8 Input membership function of LIR in a Floor

Fuzzy rule for F2 is categorized in the following diagrams: the rule for fuzzy F2 system is divided into three categories based on TP, TU and TA. After obtaining the input values from F1, it could be seen that the input membership function is categorized into availability of users (fig. 9), power consumption rate (fig. 10) and total appliances (fig. 11). This rate of each membership can vary based upon the availability of each parameter in particular room in a floor. Thus the calculated dual fuzzy membership value for each room in a floor is given to the next phase that contains fuzzy rule set.

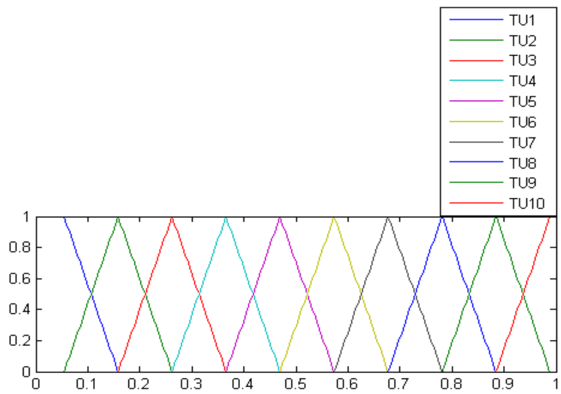

Fig. 9 Input membership function TU in each room

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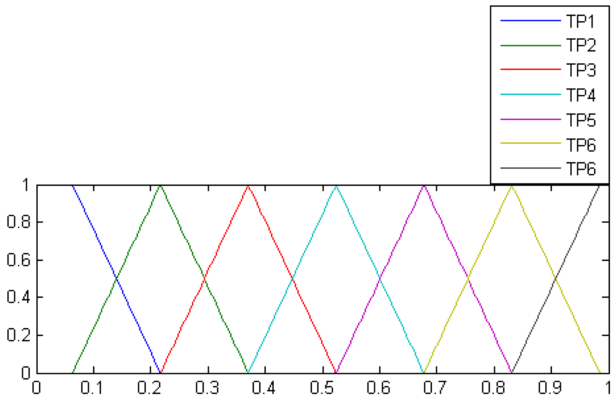

Fig. 10 Input membership function TP of each room

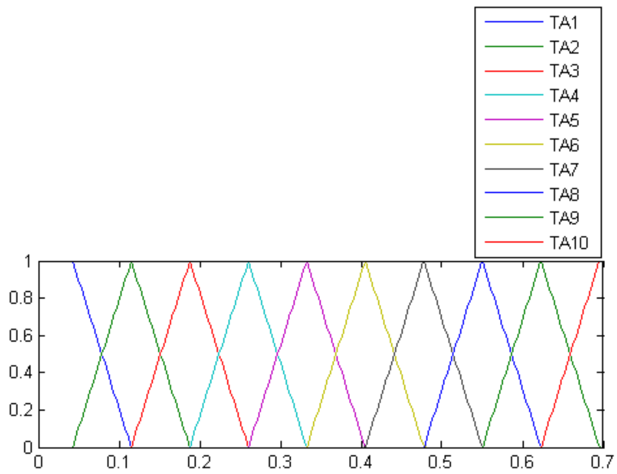

Fig. 11 Input membership function TA in each room

With the help of membership functions from the dual fuzzy inputs, rule base is created using AND function. Here all the five input membership functions like TR, room segment category, TU, TP and TA are used as a rule generation parameter where the value of each is divided into five levels. Depending on the objective to minimize the power consumption rate in a building, rules are generated. When there is no availability of user in a particular room and the devices are in ON state, the output from fuzzy is given as OFF state. Likewise if there is a mid-availability of persons in a room then the appliances that run ideally are turned OFF and the lights were made dim especially in isolated area in a floor. Similarity like this, based upon the user demand and power consumption level, the devices are made ON and OFF using control signals generated from fuzzy to the actuators using full duplex line routed through KNX protocol.

IV. RESULTS AND DISCUSSION

The designing of building automation system with KNX protocol integrated with full duplex line and fuzzy for controlling the command signals works effectively. The protocol is designed with the help of OPNET and the dual fuzzy model is created with the generation of 16 rules to control the entire operations in each room. A fuzzy model with centralized KNX server is designed as a prototype depending on the objective of the proposed research. This server is connected with the building environment through a two way duplex lines. Also, each room in the building is connected depending on the rule generated in fuzzy based on membership functions as shown in fig. 12.

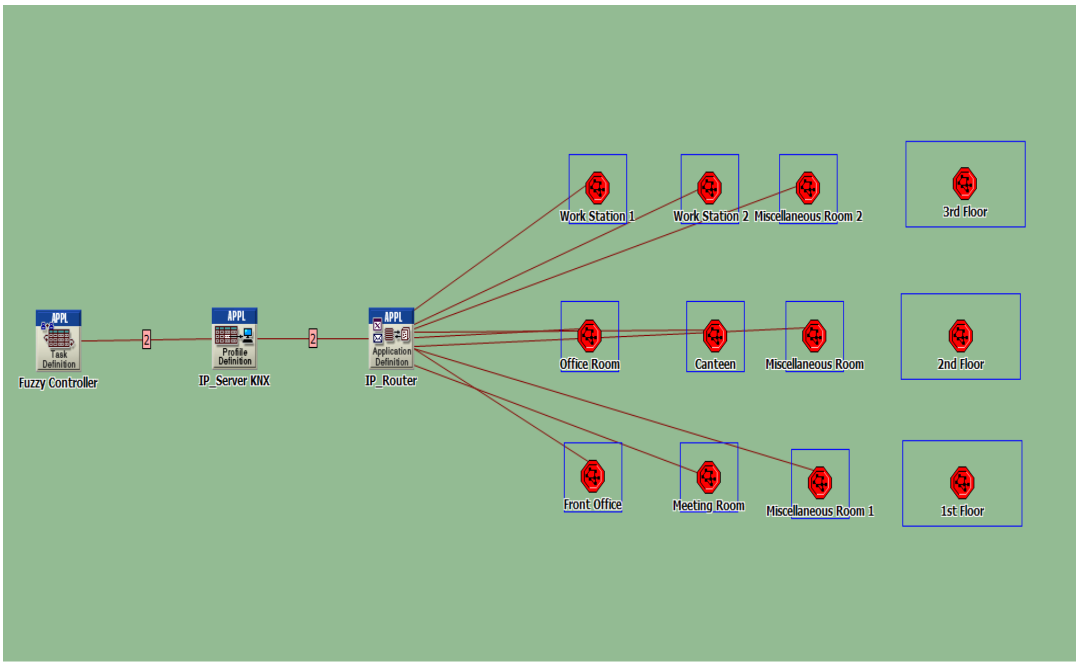

Fig. 12 Building Prototype integrated with centralized Fuzzy KNX protocol

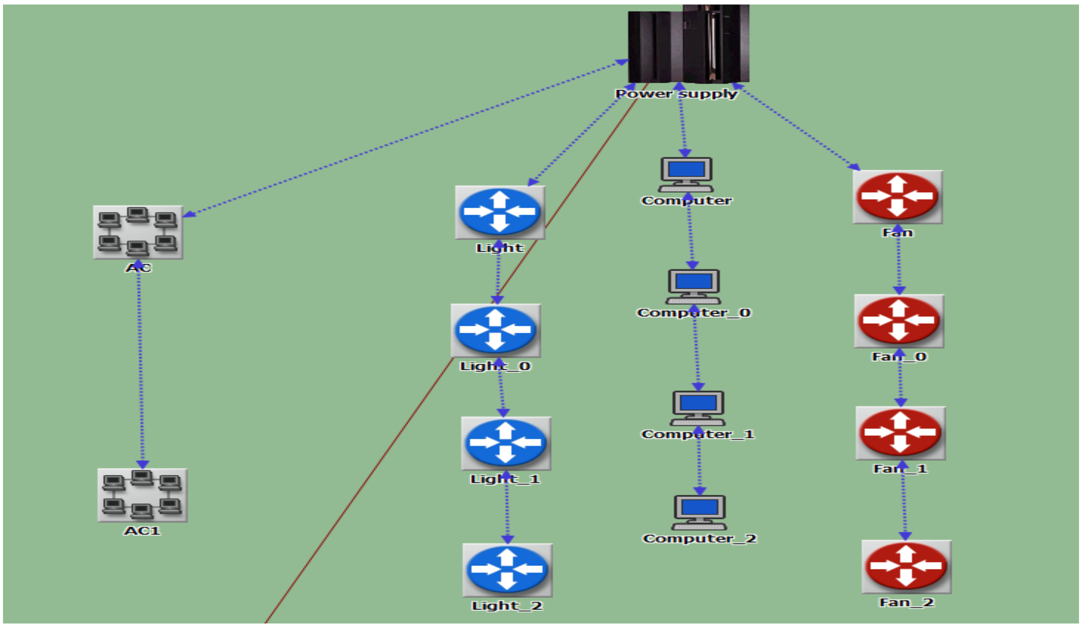

Fig. 13 The interconnection of Appliances with sensors in Typical Room environment (Work station-VIR)

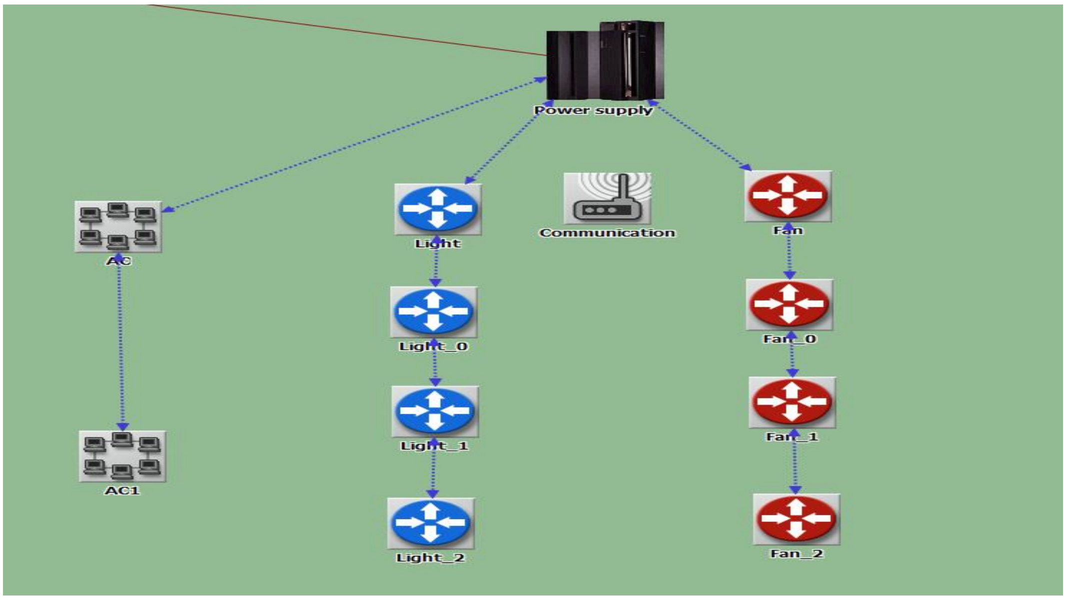

Fig. 14 The interconnection of devices in meeting room-LIR with KNX protocol

The designed prototype with sensors and actuators in each room like VIR and LIR is shown in fig. 13 and fig. 14 respectively. Here the interconnections are made with the help of sensors for each operation, its respective actuators for dimming, ON and OFF operations. Here in this prototype, each room is fixed with a maximum of 12 appliances with 12 sensors and 12 actuators placed in that environment. The control signals from all these sensors are sent to actuators, which in turn send the control signal or command signal from the room environment that like VIR (in fig. 13) to the centralized server using full duplex line. This server then sends the signal to fuzzy, where it optimizes the input membership functions with the rules and aggregating it based on the centroid. The result from the fuzzy is given as a command signal for a particular appliance to centralized server (in fig. 12). Then through IP router, the command is sent in the form of packets to the room environment, where the signal is decoded and the control is executed.

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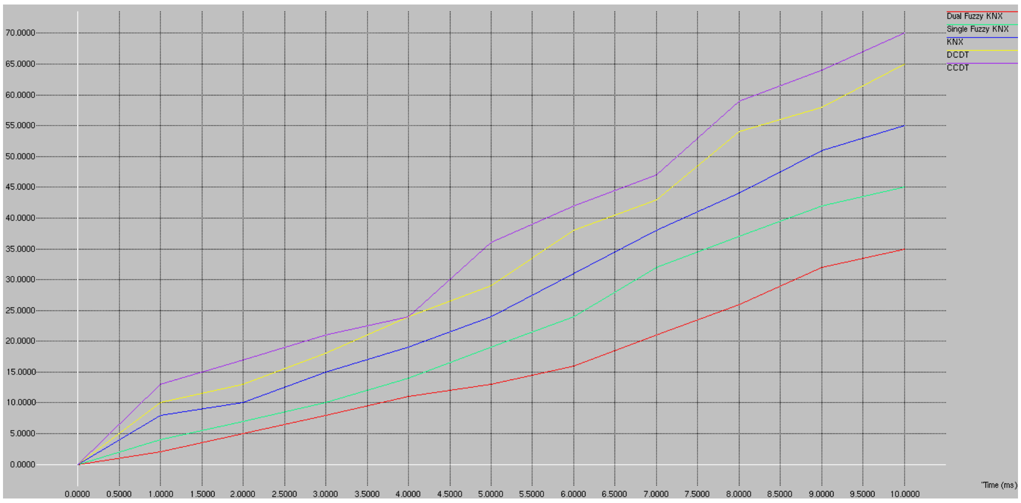

Fig. 15 Energy consumption behavior of the KNX protocol with other protocol

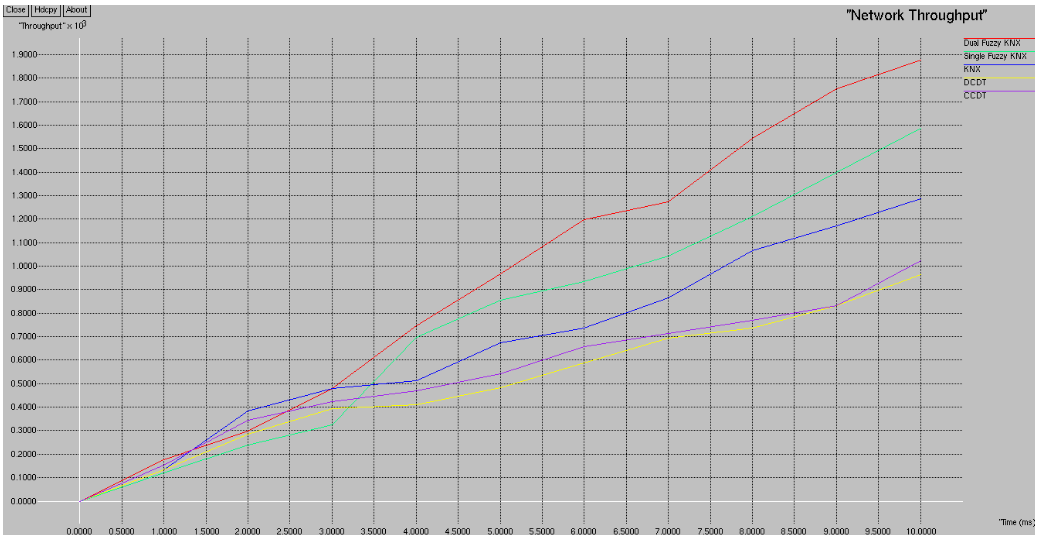

Fig. 16 Network Throughput with respect to delivery of packets and rate of collision

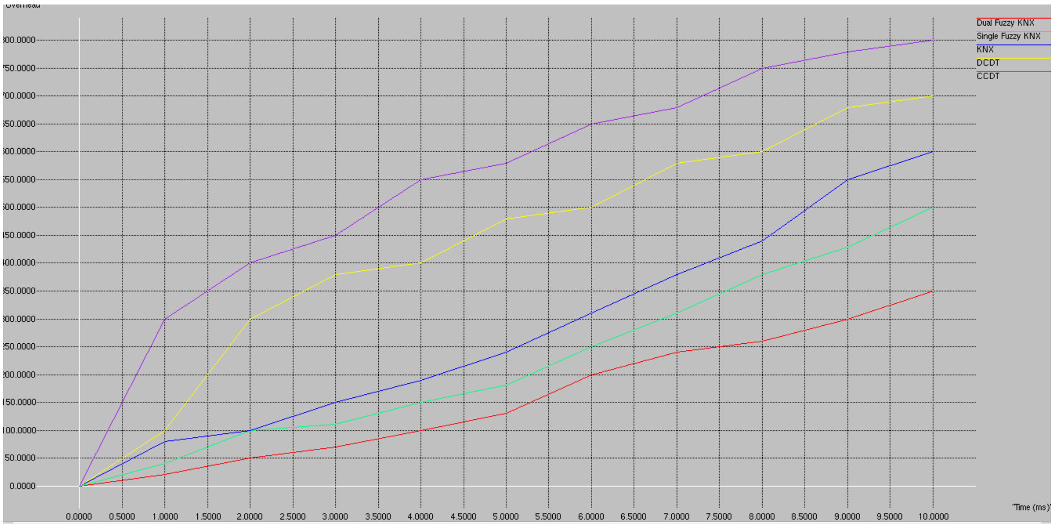

Fig. 17 Routing overhead in KNX fuzzy system in terms of full duplex channel

Thus using fuzzy over KNX protocol, we could conclude with three results based on energy efficiency, throughput and network overhead. From the results it could be found that the proposed system with Fuzzy KNX protocol performs well when compared with KNX and other building automation protocol like DCDT [12] and CCDT [13].

The results are simulated with the simulator by building KNX protocol with fuzzy model over it. The modules designed helps in achieving the task with this protocol in an efficient way. Here the system is tested with three modes: (1) the first one includes single fuzzy system that composes all the membership function defined in previous section. (2) Proposed dual fuzzy system and (3) only with KNX protocol without the intervention of fuzzy system. From the results, it could be concluded that the energy consumption using KNX fuzzy has reduced to half when compared with previous CCDT. It could also be concluded that when the fuzzy is combined in the form of dual approach, the energy efficiency has increased than with single fuzzy module. Nearly 1.6% improvement has been shown in the fuzzy KNX protocol than compared with normal KNX standard as shown in fig. 15. This proves the energy efficiency and intelligence of the proposed method. This test has been done to check the improvement done in physical layer, similarly we have done certain changes in network layer. This even has worked well when compared with previous results as shown in fig. 16 and 17. From the fig. 16, it could be found that the throughput has improved to a certain level and it is nearly increased double the time than the existing CCDT method. Also single fuzzy and KNX standard without fuzzy proved inefficient in terms of the results obtained. This case is also true in terms of network overhead where the proposed method reduced the overhead nearly half the time than the previous method as shown in fig. 17.

V. CONCLUSIONS

From the above results, it is found that modified KNX with fuzzy controller works well over an automated building environment. The use of fuzzy classification of rooms, power levels, users and appliances help in refining the input and output values. The inner most operation at both physical layer level and the network layer level helped in improving the proposed model. It is found that KNX with fuzzy performs well when compared with other building automation standards with this modified architecture. Also, the system is tested for its throughput ratio and it is found that the model delivers packets without any delay thus helping in reducing the power consumption furthermore. Moreover, this system implemented over IT infrastructure found is to be useful in a better way to reduce the electrical energy consumption level. This brings in more intelligence into a building automation environment. This work could further be improved with the help of clustering algorithm combined with fuzzy over other building atmospheres like shopping malls, hospitals, industry, schools, colleges etc.

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