Network-Independent Building Automation System

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***Abstract*— Within a multi-master environment, the Network-Independent Building Automation System (NIBAS) is structured around a hierarchical topology encompassing a management bus and a universal bus, with slave devices interconnected. This innovative system capitalizes on decentralized control algorithms, edge computing capabilities, and robust communication protocols to establish a self-reliant building automation framework. NIBAS is engineered to operate independently of traditional network infrastructures, ensuring the robustness and resilience demanded by diverse applications. By distributing intelligence across a network of sensors and actuators, NIBAS enables real-time monitoring and control of building systems, even in situations where centralized network connectivity is unavailable.**

Keywords— multi-master environment, building automation, edge computing, robust topology, robust communication, real-time system, real time monitoring, decentralized algorithm

I. Introduction

One of the primary design goals for NIBAS is to achieve simplicity without compromising robustness and security for applications that require it. The basic topology of the system is intentionally designed with some overhead to ensure resilience in the face of failures, preventing them from affecting the entire system. [1-4]

In this architecture, most end devices are connected to easily implementable buses, such as those based on RS485 based communication standards or CAN protocols. These buses then interconnect with a mesh of "Managers," which play a crucial role in data management and routing between the end devices.

This hierarchical structure ensures that the failure of individual components or devices does not lead to system-wide disruptions [5-8]. It also simplifies the maintenance and scalability of the NIBAS, making it adaptable to various building automation scenarios. Additionally, the use of well-established communication standards like those built upon RS485 and CAN enhances compatibility and ease of integration into existing systems .

II. End Device Buses

The flexibility of NIBAS extends to the physical layout of the device and management buses. There is no rigid, predefined boundary dictating where these buses should start and end. Instead, this configuration can be tailored to suit the specific needs of the user, taking into account factors such as the number of devices in the network and the physical constraints of the environment and the chosen bus technology [9-12]. The system also can be used in education for demonstrational and experimental purposes [13-15].

This adaptability allows users to optimize their NIBAS installation based on the unique requirements of their building or automation project. For instance, in a smaller-scale application with a limited number of devices, the user may choose to create shorter bus segments to simplify wiring and reduce complexity. Conversely, in a larger-scale deployment, the buses can be extended to accommodate a higher device count, ensuring efficient coverage of the entire system.

Furthermore, the physical flexibility in defining bus boundaries ensures that NIBAS can be seamlessly integrated into diverse environments, whether it's a sprawling industrial facility with extensive distances between devices or a compact residential setting with close proximity between components. This user-defined approach empowers individuals to tailor NIBAS to their specific needs, enhancing its versatility and applicability across a wide range of scenarios [16-19].

Certain end devices may be designed with redundancy in mind, offering the capability to connect to two separate end device buses. This redundancy ensures that if one bus experiences a disruption, the device can seamlessly switch to the backup bus, maintaining continuous operation. This feature is particularly valuable in critical applications where uninterrupted functionality is paramount.

Moreover, NIBAS allows for the deployment of multiple Manager devices connected to the same end device bus. This redundancy at the management level serves as a robust safeguard against manager faults. In the event that one manager encounters an issue or fails, the others can seamlessly take over the management of the connected devices and ensure the continued flow of data and control commands. This redundancy at both the end device and manager levels enhances the overall resilience and reliability of the building automation system, offering seamless error handling in a wide variety of operational scenarios.

III. Topology in Practice

A. Management mesh

The utilization of a mesh network configuration for Manager devices within NIBAS is a strategic decision driven by several key advantages. Notably, in a mesh network, the need for complex media access control mechanisms is significantly reduced. Unlike other topologies, such as a bus or star, where precise control over media access is critical, the mesh design allows for a more simplified approach to data transmission. In essence, devices within the mesh can communicate directly with one another, eliminating the need for intricate protocols to manage access to the communication medium (see in Fig. 1.).

Furthermore, the inherent redundancy of a mesh network is a pivotal feature that enhances the overall reliability of NIBAS. Within this architecture, the presence of redundant paths for data transmission between Manager devices is a fundamental requirement. Consequently, if a single connection experiences a disruption or failure, the system autonomously reroutes data through alternative paths (see in Fig. 2.). This inherent fault tolerance ensures that a failure in one part of the network does not cascade into a system-wide failure, bolstering the robustness of a NIBAS framework.

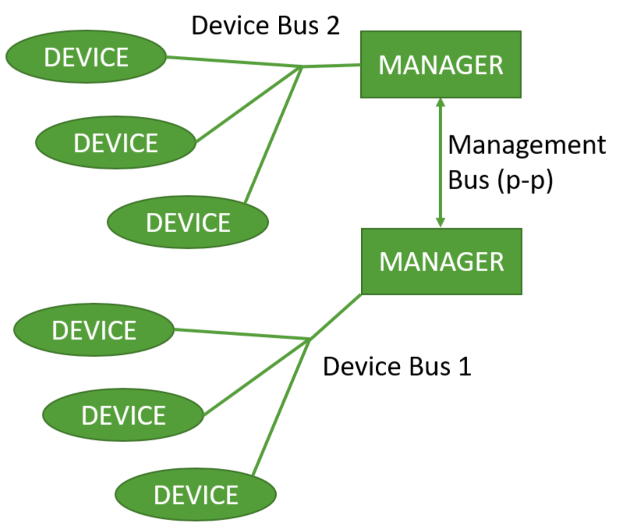

Figure 1. System topology

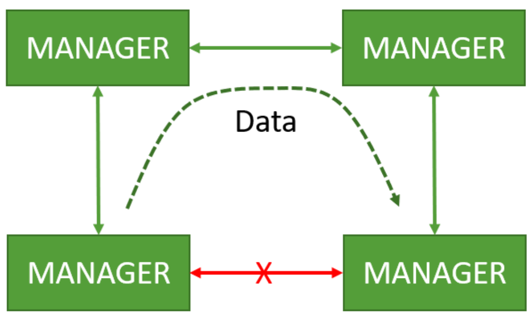

Figure 2. Error handling methodology

In summary, the mesh network topology not only simplifies data transmission by reducing the need for complex media access control but also provides a robust and fault-tolerant infrastructure. It ensures that single connection failures do not compromise the integrity of the entire NIBAS system, making it an ideal choice for building automation applications where reliability is paramount.

B. End Devices

Smart Lighting Controllers: These devices allow for intelligent control of lighting systems. They can adjust lighting levels based on occupancy, time of day, or user preferences, contributing to energy savings and enhancing user comfort.

HVAC (Heating, Ventilation, and Air Conditioning) Thermostats: HVAC thermostats equipped with NIBAS compatibility enable precise temperature control within a building. They can respond to environmental conditions and user input to optimize energy efficiency and maintain desired comfort levels.

Environmental Sensors: Sensors measuring parameters like temperature, humidity, CO_2 levels, and air quality play a crucial role in maintaining a healthy and comfortable indoor environment. NIBAS can collect and analyze data from these sensors to trigger automated responses, such as adjusting HVAC settings or activating air purification systems.

Smart Plugs: These end devices can be controlled remotely via NIBAS, allowing users to manage and monitor the power consumption of appliances and devices connected to them. They can be used for energy management and scheduling.

Occupancy Sensors: Occupancy sensors can be used to detect the presence of people in rooms or areas. NIBAS can respond by adjusting lighting, HVAC, and security settings based on occupancy patterns.

Shade and Blind Controllers: Automated window coverings can be controlled by NIBAS to optimize natural light, reduce glare, and enhance energy efficiency by adjusting shades and blinds based on external light conditions and user preferences.

An example to end devices is a multi-channel LED controller (as can be seen on Fig. 3.) that has an RS485 connection (Fig. 4.), as a proof of concept device.

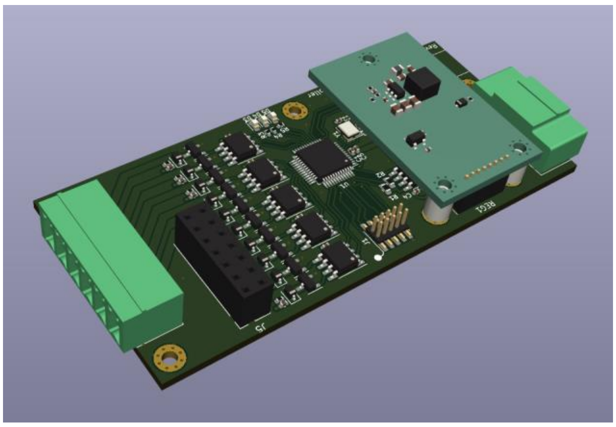

Figure 3. Prototype PCB isometric model

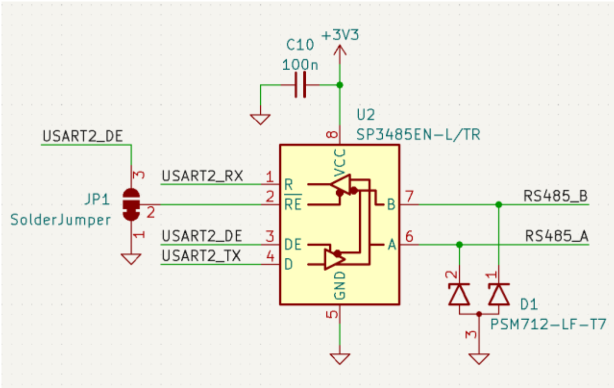

Figure 4. Communication interface design

C. Error Handling

Although the management mesh is meticulously engineered to provide redundancy and fault tolerance, it's imperative to acknowledge that even within this resilient structure, the possibility of total communication breakdown between different parts of the network must be a key consideration. While the mesh topology mitigates the risk of isolated failures affecting the entire system, it's not impervious to extreme scenarios or catastrophic events that could disrupt multiple critical connections simultaneously.

Within the local end device buses, it's important to note that communication remains uninterrupted even in the event of mesh network disruptions. Each segment of the mesh that includes a device capable of managing the remaining devices will continue to function autonomously, isolated from the rest of the network. To address potential data source cutoffs, some devices may be equipped with emergency protocols, ensuring that critical functions are maintained.

In the event of a mesh fault, users will be promptly notified of the issue through devices that display the system status. Additionally, users have the flexibility to define specific devices to execute predefined actions if a mesh failure occurs. This proactive approach empowers users to tailor the response to their specific needs and priorities, further enhancing the adaptability and resilience of the system.

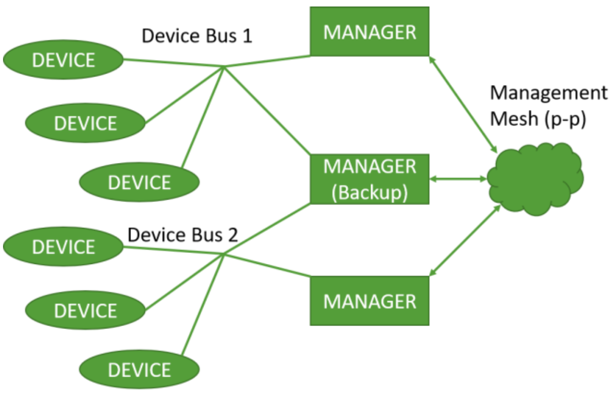

Figure 5. Multiple managers connected to the same bus for redundancy

D. Safety and security

It's important to note that security and safety devices, such as fire alarms, smoke detectors, and intrusion detection systems, are typically excluded from reliance on NIBAS. Critical applications demand a high degree of reliability and should not be dependent on the same network that handles automation and environmental control, just like the following works [20-22]. By maintaining separate, dedicated networks for security and safety, any potential issues with the automation network will not compromise the integrity and effectiveness of these crucial systems. This segregation ensures that security and safety devices operate independently, providing uninterrupted protection even in challenging scenarios.

While security and safety systems should maintain their independence, NIBAS to enhance overall building functionality and safety. For instance, in the event of an emergency, such as a fire or intrusion, security and safety systems can communicate with NIBAS to trigger specific actions, such as automatically turning on emergency lighting, shutting down HVAC systems to prevent spreading of smoke or toxic gases or disabling elevators.

IV. Conclusion

Through comprehensive experimental assessments, this paper underscores NIBAS's adaptability and reliability, offering significant potential for enhancing building efficiency, sustainability, and resilience in scenarios where network connectivity may be limited or compromised. This research contributes to the advancement of autonomous and resilient building systems, marking a significant stride toward network-independent solutions.

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