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Research Paper

An approach to hybridisation of embedded system networks

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Abstract

Embedded systems can be networked using either wired or wireless technologies. ES systems when networked using wires can communicate serially over a bus using the technologies such as CAN, I2C, USB, RS485, and Fire wire. These standards differ in many ways which include arbitration, synchronization, address resolution, timing, type of communication etc. Embedded systems can also be network using wireless technologies which exits in many versions.Several applications these days are requiring more than one communication technology. Several sub-systems are developed using a networking method and it requires that the subsystems that are networked using different technologies are to be networked further for realizing entire application. Such a network needs to deal with many of the heterogeneous communication system leading to an issue of hybridisation. In this paper various issues/approaches that need to be addressed for hybridising of the ES networks have been presented.

Keywords: *ES Networking; Hybridization; Interconnection of Heterogeneous Networks.*

1. Introduction

Networking embedded systems can be achieved through a wired or a wireless network. Many communication technologies are in existence considering both wired networking (CAN, USB, I^2C, RS485, Fieldbus, MODBUS, Ethernet etc.) and wired networking (WI-Fi, Bluetooth, ZigBee etc.) and a combination of both wired and Wireless networks.

Both wired communication technologies differ in many ways considering address resolution, length of communication, number of devices that can be connected to a network, synchronisation, timing, flow control, congestion control, bus width, isolation, noise management. Even the wireless communication technologies also differ in many ways which include communication length, noise, extent of shadowing, extent of reflection etc.

In the past and embedded application is implemented using only one communication technology and using the same version of communication protocol. Not much importance is given to find the suitability of a technology for implementing a given application.

With more and more complex applications being implemented in the automobile, space management, home automation, industrial process automation domain, the trend has been to use several sub-nets contained in total networks that is established for implementing a distributed embedded system. Each sub-net is generally implemented using a different technology making it complicated to establish connectivity and interoperability among the sub-nets formed within a network.

One solution to tackle the heterogeneity among the networking system is to implement hybridisation that helps in establishing the networking and communication among the heterogeneous systems. The issue of hybridisation must take into account the heterogeneity among the communication technologies and also in between the protocols used for effecting communication. Heterogeneity might exists even if the same communication technology is uses when different versions of the same protocol or different protocols are used for effecting communication.

There can be many hybridisation strategies that can chose for implementation. It is important asses each of the hybridisation process and finds the most suitable one for a specific application and then proceed to design and development of hybridisation by making suitable changes to the main network so that the issue of heterogeneity is properly tackled. In this paper various approaches to achieving hybridisation is presented.

2. Relative work

The speed of communication through I2C and RS232C get affected due to the existence of complex electromagnetic environment as existence of such an environment will result into improper disposal of the signals to the interfaces. Improper disposal of electromagnetics will result into low speed and reliability. Several methods are to be introduced to tackle the issue of speed through proper buffer management [1]. When a RS 232c interface has to be used for connecting a device to an MCU and if the same device has to be connected to ES networking many complicated issues arises including the issue of speed of communication and also effective the data communication rates.

Using wireless technologies for the development of distributed embedded systems is challenging compared to wired networks due to existence of uncertainty and less reliability that is caused due to magnetic interference, fading, reflection etc. Predictability of wireless communication is an issue. It becomes quite risky for a system when it has to meet some safety critical requirement by receiving data through a wireless network. The uncertainties existing with the wireless communication can be solved through use of hybrid models or undertaking hybridisation of architectural mod-

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els. The concept of hybridization is more prevalent in the automotive domain where everything must work perfectly in spite of uncertainties. Hybridisation helps when the communication has to happen in uncertain situations. An architecture has been presented that can be used to implement applications requiring the concept of Hybridisation. There are many interface issues that must be considered and handled through a programming model which makes the system hybridization-aware [2].

Two standards are frequently used which include fieldbus and CANbus for implementing industry based applications, fieldbus standards are not uniform and greatly differs from industry to industry. Communication between the devices using fieldbus as such is complicated. In industry both the bus based networking systems are frequently used. This has led to a requirement of converting one type of communication to the other which can be achieved through protocol conversion. Protocol conversion interface can also be designed and implemented at hardware level [3].

CAN bus based communication can be used for networking embedded systems. The developers needs to understand the CAN protocol, Interface, controller and Physical connections before the applications can be developed using CAN based communication. Implementing CAN based communication at gross root level is complicated and also needs through testing. The development of applications using CAN shall be made to be simple through CAN module which can be used through function calling just for transmitting and receiving information. In the CAN module all is built using some function that abstracts the real implementation of the protocol. The CAN being a protocol suite can be integrated with any embedded system Software. Sending and receiving the data can be achieved through CAN module [4]. When CAN is to be used along with other communication protocols such as I^2C, protocol conversions can be implemented at function level instead of gross root level. If another module that abstracts I2C communication is developed then protocol conversion can be achieved at function level

A separate device can be designed and developed that has the capability of doing protocol conversion using multiple Microcontroller based systems, high speed dual port RAM data sharing technology, and real time mutli tasking operating system µC/OS-II. A protocol converter that helps communication between RS232C and RS485 has been developed that can be implemented within intelligent instruments, data acquisition systems etc.[5] The device can be interfaced with a remote monitoring system through Ethernet based communication. In this way serial devices can be connected to the network control layer. This device developed this way has high reliability and real-time performance and realize data exchange, data sharing and information processing among multiple Micro controller based systems

Fieldbus protocol as such is nonstandard and has been implemented in multiple versions. There is also a problem of interconnecting different fieldbuses. When two networks are built using different fieldbus communication protocols protocol conversion is needed. ARM controller can be sued for achieving the conversion. The protocol conversion is achieved through development of a protocol conversion gateway using a standard data packet. The method is not limited to one to one conversion and is independent of the location of the bus and the kind of protocol used by the fieldbuses [6].

An USB and I2C protocol differs in many aspects considering the way the communication is undertaken. The data packet formats, length of the network, number of devices that can be connected, number of master, bus arbitration, synchronisation method, address resolution, flow control etc. differs a lot. A mapping between I^2C and USB has been done both at the hardware and software level. The software structure that can be used for achieving the conversion has been presented [7].

Modbus and Profibus are two communication systems used for achieving the industrial automation. Both the communication methods are widely used in industrial control field. However these two buses cannot be connected directly due to existence of great variance between them. A gate way is needed for connecting two different buses through with protocol conversion can be carried. A gate way is developed using AT89C52 Microcontroller. Profibus and Modbus are two more common industrial field bus, they were widely used in industrial control field. Because the two buses can't interconnect with each other, we design a gateway for Profibus and Modbus to achieve Profibus and Modbus protocol conversion. The semen developed SPC3 is integrated with the Micro Controller [8].

Many types of sub-systems are to be developed and implemented using different communication systems when it comes to implementation of systems such as s Flight control, banking, medical, and other high assurance systems which needs to be implemented most precisely. Since communication system uses different signalling, sheathing, noise filtering, signal isolation etc., one should design and develop the system such that one sub-system does not interfere with the other. Tracking information flow at hardware level is one method that can be used to detect and filter the interference of one communication system with other. Gate-level information flow tracking (GLIFT) system is developed that provides a methodology for testing information flows that takes place within I2C and USB. Time division multiple access (TDMA) has been used that can isolate a device on the BUS from the flows [9].

Industrial Ethernet technology (EPA) and Modbus communication technology (MODBUS) are quite frequently used communication systems to implement industrial processes. No direct communication as such can be carried in between these two systems as there is no direct compatibility between them. A communication gateway is developed for achieving the required interface between these two technologies. A gateway has been developed using ARM based micro controller and µCOS real time operating system. Bidirectional communication can be achieved through use of the gateway. The communication gateway can provide a stable, secure, real-time and flexible solution for process control of the power plants [10].

Two types of industry specific communication systems are used in the power sectors which are meant for National power dispatching and for controlling the wind mills. For providing the integrated energy management system theses communication systems must be interfaced with each other. A gateway has been developed for to achieve protocol conversion that implements functions like interconnectivity, protocol data type and format conversion and scaling, data validation, management of local/remote commands, simulation of data packets transmission and requests, communication packets analysis and redundant communication links [11].

Fieldbuses are used in industry for exchange of data between several microcontrollers and field devices through effecting communication among them. Many versions of the fieldbus communication systems exist. Designing a communication system for effecting communication among the devices that follow different fieldbus communication standards is complex and generally leads to complicated implementation of hardware and software. An efficient communication interface id need for implementing a reliable system using diffident fieldbus communication standards. CAN bus is also being used these days for implementing many of the industrial process. There is a need to interconnect between CANBUS and MODBUS. The communication protocols are to be mapped considering different aspects of communication and then an interface is required to be developed. An interface that interconnects both the bus based communication systems has been presented. [12]

Many individual blocks of logic exist on system-on-a-chip and they must be integrated to achieve overall desired functioning of a system which is built on a single chip. The integration between the modules is not possible some time when the modules follow different IP protocols. In such case, IP conversions are required. Many conversion algorithms exist that help converting one IP to another. Implementation of a converter on a chip is rather complex IPs can be modelled through use of several layers recommended by OSI. The conversion algorithms existing as date focus on single layer defined in a OSI system or sometimes blur the boundary that exists among the layers. A formal framework has been pre-

sented that allows development of converters for IP protocols that are modelled at different layers of OSI system. Any existing conversion algorithm can be implemented in any of the OSI model using the framework [13].

Rs232C Interface is generally in-built into most of the Microcontrollers for effecting the serial communication and the same can be implemented as bus based communication using RS485 based wired communication. Implementing RS485 based networking is quite simple and feasible as most of the controllers are provided with RS232C Interface which can be converted into RS485 interfaces using hardware converters which are readily available in the market. RS485 based communication suffers from heavy overheads due to requirements of transmission the device addresses along with data. If RS485 based communication is implemented using star topology using HUBS, the overheads due to address transmission along with the data gets eliminated. The implementation of HUB based RS485 has been presented and the same is experimented on pilot projects that monitors and controls temperatures within a nuclear reactor system. To the process of communicating through RS485 based communication many new inventions ahs been added which include addressing the devices on the network, message flow control architecture and data packet design [14].

A distributed embedded system can be implemented through I^2C communication protocol. Investigations are to be carried for realizing a distributed embedded system which includes finding suitable architecture, design of messages, designing networking topology, message prioritisation and design of data packets. Some of the microcontrollers may not have I^2C interface and therefore becomes infeasible to be connected on to an I^2C networks. Such microcontrollers as such are regarded as heterogeneous. This issue of heterogeneity must be addressed so as to connect any of the microcontroller based system to be made as note on I2C based network. Heterogeneous issues that exeunt among the different microcontroller based networks have been addressed. New methods have been presented that are related to message design, message flow control, protocol conversions have been presented. Differences exists among different distributed systems using which the same application is implemented in terms of the kind of conversions to be carried varies greatly. Many masters can be made to be working on a I2C network. The way the communication is effected depends on the number of masters and slaves that get connected to the network. Most suitable communication archiecure for implementing a distributed embedded system using I2C communication systems has been presented [15].

Networking heterogeneous embedded systems is a challenge. Every distributed embedded systems requires that the network is designed specifically considering the heterogeneity that exits among different Microcontroller based systems that are used in developing a distributed embedded system. Communication architecture, which considers the addressing of the individual systems, arbitration, synchronisation, error detection and control etc. needs to be designed considering a specific application. The issue of configuring the slaves has to be addressed. It is also important that the messages, flow of the messages across the individual ES systems must be designed. Every distributed embedded system is different and needs to be dealt with separately. This paper presents an approach that addresses various issues related to networking distributed embedded systems through use of universal serial bus communication protocol (USB). The approach has been applied to design a distributed embedded that monitors and controls temperatures within a Nuclear reactor system [16].

Implementation of many applications that relates to various domains that include safety and mission critical systems, space management systems automobile systems etc., requires the development of distributed embedded systems. The performance and response requirement of such systems leads us to the development of distributed embedded systems using specific communication protocol. Networking embedded systems leading to the development of embedded systems can be achieved through many of the wired communication systems that include USB, CAN and I^2C. All the communication produces effective results if all the devices connected on to the network have the same communication interfaces based on the communication protocol uses. However the situation is different when heterogeneous embedded systems are to be connected into a network by using a specific protocol. Many issues are to be addressed when communication has to be effected among the heterogeneous devices that are connected on to the same network which include system architecture, networking, flow of messages, arbitration, error detection, address resolution, flow of control etc. Networking of distributed embedded system using CAN protocol has been presented considering various kinds of heterogeneous devices. Few enhancements have been added related to message flow architecture, arbitration and data flow [17].

The multiprotocol Interface performs conversion of multiple protocols into single standard protocol to achieve interoperability between the devices involved in the communication. A designing of Multi-protocol Interface Device to perform conversion of Ethernet, USB V2.0 and SPI to RS 232 using DSP processor has een presented [18].

Many systems are being implemented such as driver assistance system, infotainment etc., within automotive systems that require large amount data to be collected, processed and use the same for controlling the very automotive system itself. High speed communication is required among the sub-networks implemented within an automobile system for proper and reliable operation. The speeds that can be sued using the communication systems as such are quite low and under those circumstances it is not possible to guarantee proper operation of those systems. A technique called "BroadR-Reach" can be sued for improving the performance of in-vehicle networks. The techniques enable Ethernet communication over single pair of Unshielded Twisted Pair (UTP) wires. Ethernet provides much faster transfer rates and a larger payload than existing protocols such as Controller Area Network (CAN), Local Interconnect Network (LIN), and FlexRay.

Real-Time Ethernet (RTE) is gaining widespread use because it is based on Ethernet. RTE provides improved performance over existing fieldbus for applications in automation networks, such as for highways, city surveillance, power substation, factory automation. A gateway between RTE and RS485 has been presented. A gateway based on BroadR-Reach has also been presented for bridging between Ethernet and RS485 [19].

ZigBee and Wi-Fi wireless communication systems are being used widely in many of the communication system and especially so in the field of IoT. Zigbee-WiFi hybrid communication is one of the most important requirements that must be met when both the communications systems are used interchangeably. A protocol conversion method has been presented that converts 802.15.to 802.11b and vice versa. The converter resolves mismatch that exists in physical layer, MAC layer and address mapping. The converter is found to be effective considering three indexes that include network connection speed, SINR (signal interference noise ratio) and network delay [20].

Industrial Ethernet technology and fieldbus technologies co-exist as on date for automating industry processes. A uniform network cannot thus be implemented due to existence of varied communication systems which have no means of communicating among those systems. a protocol conversion gateway has been presented that does bidirectional conversion between MODBUS and PROFINET has been presented. The original MODBUS communication protocol has been reformed so that the gateway can realize the function of MODBUS device to get access to Industrial Ethernet [21].

3. Investigations findings

Several approaches can be resolved for the purpose of achieving hybridisation. Some approaches include Device level hybridisation, Master level hybridisation, Multi master level hybridisation and gateway level hybridisation. Hybridisation can be completely implemented with the hardware or the software or use of both. The

software level of implementation can thought over as middleware. Each of the approaches are presented in the sections below, each approach have related to pros and cons. At the ground level the approach that best suits an application must be selected.

3.1. Device level hybridisation

One level of hybridisation between two heterogeneous networking systems could be achieved through a device having both the networking interface. A middleware resident as a firmware within the device shall be implemented with a conversion software which will be designed for converting one kind of Communication protocol to another. One device must be developed for each of type of protocol conversion leading to the requirement of development of many devices developed. It is very difficult to maintain protocol converter built into each of the device. An example implementation of device level Hybridisation is shown in Figure 1.

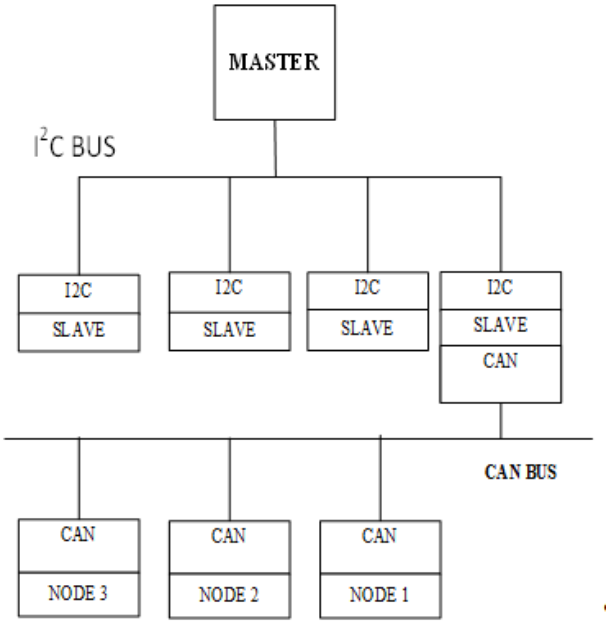


Fig. 1: Hybridisation through A Device.

3.2. Master level hybridisation

Master in this case is an embedded system of recent origin that has both I^2C and CAN ports. In the master affirm is developed that does the conversion of one protocol to the other. The master being one of the devices on both the networks dealing with the traffic on either side gets overloaded. Response times fall very heavily in this case. The converter module could be standard module and can be incorporated into the firmware using callable interface provide the conversion module is developed using open source using a programming language such as Python. An example implementation of Master level Hybridisation is shown in Figure 2.

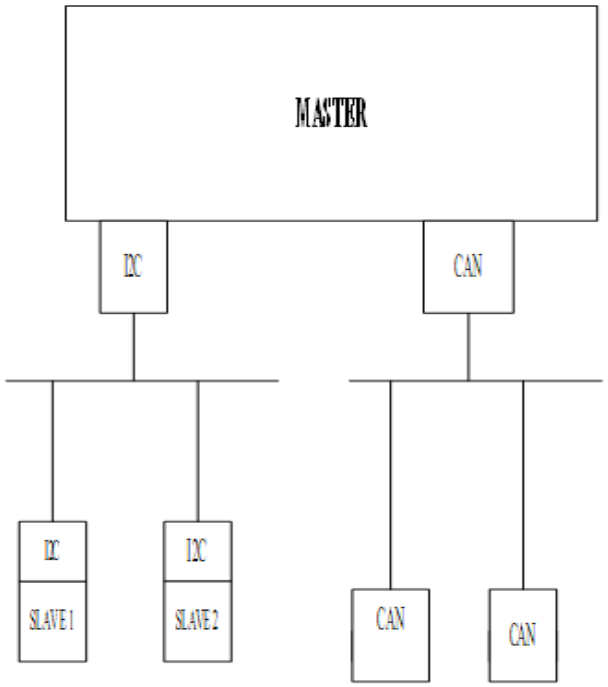


Fig. 2: Hybridisation through A Master.

3.3. Multi master level hybridisation

Two independent networks each managed by a master can be interfaced with each other through a RJ45 interface that connects the masters to a LOCAL area network. The speed of communication using RJ45 is rather faster multiple times compared to either I^2C or CAN based communication. However protocol conversion needs to be done at two locations to establish bidirectional communication. An example implementation of Multi- Master Level Hybridisation is shown in Figure 3.

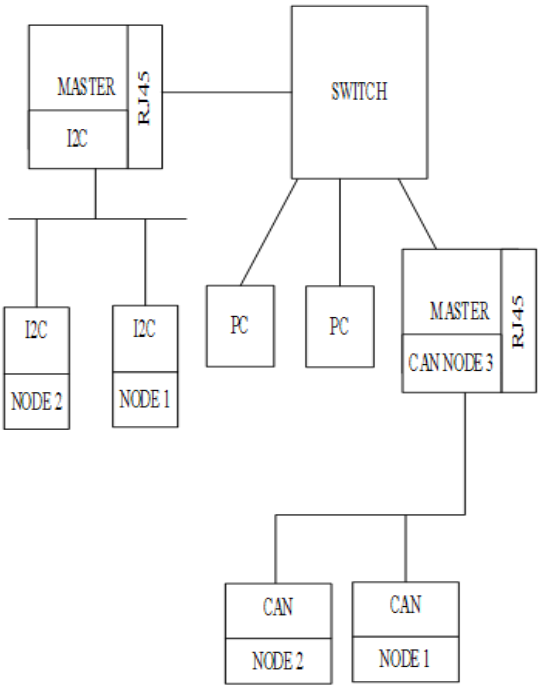


Fig. 3: Hybridisation through Multi-Masters via Local Area Networks.

3.4. Gateway level hybridisation

A gate way is a device that has number of interface connected to it. The gateway as such can be developed using high speed embedded controller which acts ad a communication controller. Communication between two heterogamous embedded networks can

be handled using the gate way and the native interfaces of the masters of the networks. Masters communicates with the gateways using native interface and no protocol conversion is required on the master side. Protocol conversion actually takes place at the gateway level. This kind of protocol conversion to accommodate heterogeneity appears to be most reliable. An example implementation of gateway level Hybridisation is shown in Figure 4.

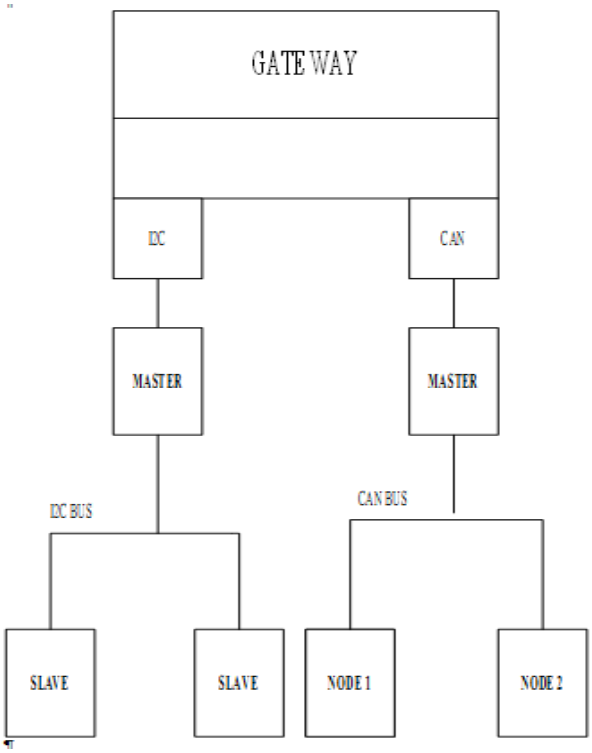


Fig. 4: Hybridisation through Gateways.

3.5. Hybridisation through multi technologies

The hybridisation that we have discussed so far is simply based on wired communication technologies. However two different types of technologies are to be implemented in respect of some kind applications which require remote monitoring and controlling. Protocol conversions in that case are generally undertaken using the hardware devices such as Access points. Figure 5 is an example implementation of hybridisation when two different communication technologies are used.

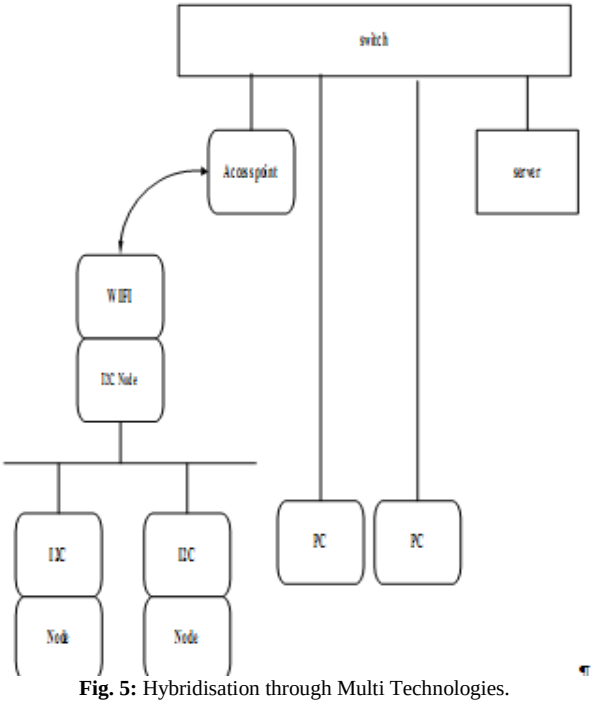


Fig. 5: Hybridisation through Multi Technologies.

4. Comparison of approaches to hybridisation

The comparison of different approaches to hybridisation is shown in Table 1.

Type of Hybridisation	Hardware level implementation	Software level implementation	Both hardware level an software level implementation	Cost escalation	Effect on response Time	Enforcement of security	Maintainability
Device Level	Yes	Yes	YES	Less	Less	weak	Good
Master Level	No	Yes	YES	Average	Average	OK	Less
Multi-master Level	No	Yes	YES	More	More	Good	Average
Gateway level	No	Yes	YES	More	More	Good	More
Multi technology	No	Yes	Yes	Heavy	More	Good	Less

From the table-I it can be seen that every approach have some pros and cons. A trade-off has to be made before deciding on the approach to be chosen for implementing hybridisation.

5. Conclusions

Many applications are being implemented in different domains that need the use of several embedded wired and wireless networks and different kinds of communication protocols. Heterogeneity exists even when the same communication technology is being used to use of different versions of the same protocol or different forms of the same technology for instance ZigBee and Wi-Fi.

Heterogeneity per say not only exists due to use of different hardware but also due to use of different communication protocols that may all belong to the same communication technology.
Hybridisation is one of the means of tackling the heterogeneity within and in between the communication technologies. There exits many approaches for implementation of hybridisation and one has to choose the best option based on the kind of application implemented using several subnets each implemented through communication technology.

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