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VIRTUALINK-40: WIRELINE NETWORK EMULATION USING WIRELESS MODEMS

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Abstract **- This paper presents the architecture and operation of the VirtuaLink-40 wireless modem. VirtuaLink-40 can be used in home, office, enterprise and industrial environments to extent the capabilities of existing applications that use the telephone system as their information transmission medium.**

1. Introduction

The problem of interconnecting equipment and devices belonging into different communication systems has been addressed extensively lately [1]. The 'global communication system' includes medium and high-speed local area networks, wide area networks, wireless networks etc. The interfacing of different communication systems is mainly implemented by interconnecting central switching facilities. Wireless networks, like CDPD [2] and Mobitex [3], offer a wide range of services and the required user mobility. This is performed by connecting their base stations with nodes of public communication systems. The introduction of Personal Communication Services will expand the flexibility and functionality of notebooks, personal assistance devices etc., thus enlarging an already big market [4]. Such a system requires a new communication infrastructure to be installed and new operational procedures to be established. The cost and time required for such a development is not affordable by a large number of users requiring a limited set of functions at a minimum system cost. Residential, business and small enterprises are among the users that require limited system functionality at the lowest possible cost. This paper describes the architecture and functionality of a system, that extends the telephone network capability to exchange data to wireless users.

2. System Overview

Most users use, or they could use, telephone line modems for data transfer and a lot of their application software is based on this functionality. They use either common telephone lines or dedicated leased lines and their protocol stack is commonly based on a connection oriented service at the lower layers. The drawback of this approach is that, it requires a telephone socket for accessing the network, thus minimizing its flexibility. This disadvantage can be overcome by extending the accessibility of a specific telephone socket, by using wireless communication links. Such a network should combine existing public switching telephone networks with wireless networks, providing a unified communication system to the user.

VirtuaLink-40 is a wireless modem, developed to address the wireless connection to such a communication system. VirtuaLink-40 modems are directly interconnected and form a small scale local area network, since they implement more sophisticated communication functions than the Public Service Telephone Network (PSTN) modems, and no central switching system is required in between. Depending on the functionality of the higher level software, VirtuaLink-40 modems can support multiple concurrent data connections with the same or different remote modems. They can be combined with PSTN modems to form inter-networking devices, that transparently interface a local wireless network to PSTN. The wireless modems have the same user interface with the PSTN interface, which is based on the AT commands de facto standard [2].

A possible network architecture that combines PSTN and wireless networks is shown in the figure 1. The network consists of multiple wireless subnetworks, operating independently, and the PSTN which is used to interconnect them.

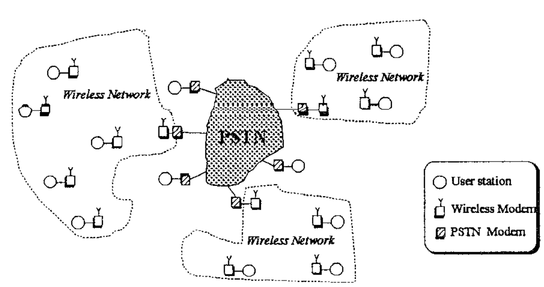

Fig. 1. The network architecture

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Each VirtuaLink-40 modem has a user configurable address which is unique in the respective subnetwork and becomes unique in the whole network architecture, when it is combined with the subnetwork unique address. The address of each subnetwork is defined by the respective PSTN address (telephone socket), where the subnetwork is connected. If a subnetwork is not directly connected to the PSTN, then its address is defined by the combination of the address of the VirtuaLink-40 modem, that interconnects this subnetwork with a subnetwork that is connected to the PSTN, and the address of the attached subnetwork. In case there are two or more alternative routes for interconnecting two end-systems, the user originated the connection determines the preferred path.

The wireless subnetworks use a network protocol for single, group and broadcasting message delivery. The transport protocols ensure reliable message delivery with different message types and characteristics. The subnetwork protocols also provide management and diagnostic functions and message authentication. The system provided services are distinguished into three categories: application services, management services and configuration services. The application services use a set of protocols for supporting widely used applications. These services include connection establishment, file transfer, terminal access etc. and custom configured services, like collection of sensorial data. The management services include security services, medium access and transmission services, while the configuration services include set-up of protocol parameters, testing procedures etc. During connection set-up, protocol dependent parameters are negotiated and thus, reliable, transparent data transfer is achieved.

Although the system is based on connection oriented data transfers, the wireless network uses a multi-access protocol, based on the CSMA protocol, which is upgraded to the connection oriented service by the data link and the transport protocols. Whenever a logical connection is established between two adjacent wireless nodes, a connection monitoring process is activated in both stations. In this case, if one of the nodes does not respond to periodically generated maintenance commands, a 'hang-up' signal is generated to the respective user. Each wireless modem supports up to 16 concurrent connections within the same or other subnetworks.

The relay functions required for inter-working between a wireless network and the telephone subnetwork are implemented by sophisticated bridges. These bridges perform the low-level communication signalling, user selectable flow-control protocols, and error control procedures. They are based on commercially available PCs and can support the communication of one or more subnetworks with multiple telephone connections.

3. Modem Architecture

The VirtuaLink-40 modem uses a powerful microcontroller to execute all communication protocols and a real-time multi-tasking kernel (SOSystem) to handle all timing functions that are related to the protocol state machines. Its RF interface has been based on a GMSK modem and on an enhanced serial communication controller. The transmission speed is 14.4 kbps using 25 kHz channel spacing. The used data framer allows the implementation of various standard protocols and the development of custom protocols. Among the supported protocols are the IBM Bisync, SDLC, HDLC and ADCCP protocols [1]. The RF transceiver is a half-duplex synthesized module with user programmable carrier frequency and transmission power, operating at the UHF band. Up to 800 different channels can be selected by the VirtuaLink-40 user.

The Simplified Operating System (SOSystem) consists of a priority-driven scheduler and three resource managers, the event manager, the memory manager and the time manager. The scheduler supports a limited set of real-time multitasking procedures and a pre-emptive priority driven CPU allocation mechanism. The Event Manager is used for inter-task communication by allocating static buffers and using an ownership control mechanism. The Memory Manager is used for associating parts of the MCU memory map to specific connections. The Time Manager notifies the tasks for the expiration of predetermined time intervals and controls the Connection Supervisor task, which emulates the wire-line signalling and monitors the status of each active connection.

4. Conclusions

The paper presents the VirtuaLink-40 modem, in terms of hardware and firmware, and the wireline network functions that are emulated using this modem. This modem can be used to set-up wireless networks that emulate the telephone network functionality and to extend data transmission capabilities of the telephone network to wireless users.

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Wireline Network Emulation Using Wireless Modems

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Abstract *- This paper presents the architecture and operation of the VNet system and its basic components, the VirtuaLink-40 wireless modem and the VNet bridge. The VNet is used in the home, office, enterprise and industrial environments in order to provide mobility to applications that use the telephone system as their main communication system. The network emulation functions are implemented by co-ordinating distributed networking entities that belong to each wireless modem. The VNet bridges are used to interface the telephone network with a number of wireless networks and are used mainly for store-and-forward purposes.*

1. Introduction

The problem of interconnecting equipment and devices belonging into different communication systems has been addressed extensively lately [1]. The 'global communication system' includes medium and high-speed local area networks, wide area networks, wireless networks etc. The interfacing of different communication systems is mainly implemented by interconnecting their central switching facilities and by implementing protocol conversion functions on these equipment. Wireless networks, like CDPD [2] and Mobitex [3], offer a wide range of services and the required user mobility and their wireless units communicate via the network base station, which is also used for interfacing with nodes of public communication systems.

The introduction of Personal Communication Services will expand the flexibility and functionality of notebooks, personal assistance devices etc., thus enlarging an already big market [4]. Such a system requires a new communication infrastructure to be installed and new operational procedures to be established [5]. The cost and time required for such a development is not affordable by a large number of users requiring a limited set of functions at a minimum system cost. Residential, business and small enterprises are among the users that require limited system functionality at the lowest possible cost [6]. This paper describes the architecture and functionality of a system, that extends the telephone network capability for data exchange to wireless users. This system requires the minimum additional hardware for providing the networking functionality and it does not require any modification on the existing application software, since it contains all required functions to emulate the telephone network operation in the wireless environment.

2. System Overview

The Public Service Telephone Network (PSTN) provides the basic service for connecting two remotely located users. Most people use, or they could use, this service for transferring data between two remote sites and a lot of their application software is based on this capability. Internet access from home is achieved using this capability, which allows the temporary connection of the local computer to the Internet service provider, by using telephone line modems on both sides. Many small scale enterprises use the telephone network in order to interconnect remote sites, either temporarily or permanently. The connection can be achieved by using either common telephone lines (dial-up lines) or dedicated (leased) lines and the application protocol stack is commonly based on that connection oriented service. The drawback of this approach is that, it requires a telephone connection for accessing the network, thus minimizing its flexibility. This disadvantage can be overcome by extending the accessibility of a specific telephone connection, by using wireless communication links. Such a network should combine existing public switching telephone networks with wireless networks, providing a unified communication system to the user. This new system must provide the same service to the end user as the ordinary telephone network without the fixed location constraint.

This new system, the so called VNet, is implemented by using a new wireless modem and a bridge for interconnecting the wireless network with the PSTN. The wireless modem (VirtuaLink-40 [7]) was developed to address the wireless connection to such a communication system by implementing, among others, a subset of the network emulation functions. The wireless

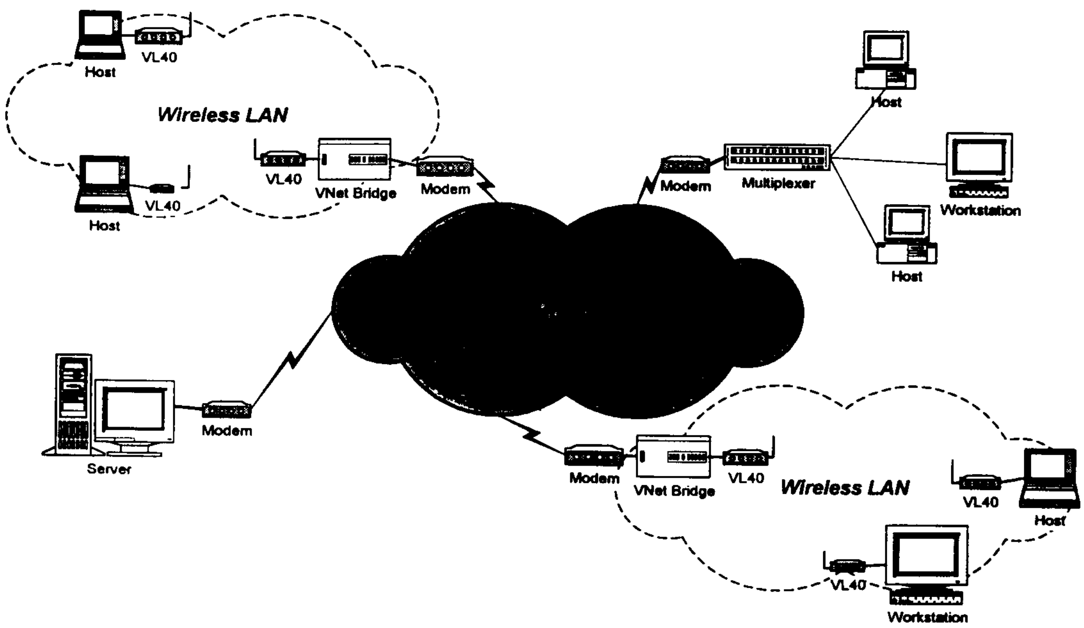

Fig. 1 The VNet System

modems are directly interconnected and form a small scale local area network, since they implement more sophisticated communication functions than the PSTN modems, and no central switching system is required in between. Depending on the functionality of the higher level software, the wireless modems can support multiple concurrent data connections with the same or different remote modems. They can be combined with PSTN modems in a bridge configuration to form inter-networking devices, that transparently interface a local wireless network to PSTN. The wireless modems have the same user interface with the PSTN modems, which is based on the AT commands de facto standard [2].

The relay functions required for inter-working between a wireless network and the telephone network are implemented at the VNet sophisticated bridges. These bridges perform the low-level communication signalling, user selectable flow-control protocols, and error control procedures. They are based on commercially available PCs and can support the communication of one or more networks with multiple telephone connections.

A possible network architecture that combines PSTN and wireless networks is shown in Figure 1. The network consists of multiple wireless networks, operating independently, and the PSTN which is used to interconnect them. Each wireless modem can be logically connected with:

- another wireless modem in the same network,
- a wire-line modem on the PSTN, or
- a wireless modem in another wireless network.

The VNet user provides the destination of the remote unit, and the VNet devices implement the network signalling and management functions. The network allocates part of the system resources to a specific connection (bandwidth on the wireless part, direct cable connection on the wireline part) and supervises them during that connection.

3. Network Emulation Functions

The wireline modems use the telephone network functions for providing their services to the host device. The network implements the signalling functions, establishes and releases a connection and provides all indications for the connection status. Whenever the remote unit is not available during the connection set-up, the telephone network switching equipment generates a signal that informs the caller that the remote unit is not available. If a connection has been interrupted due to network problems, the switching equipment generates another signal that informs both sides that the communication is not capable anymore and that they have to re-establish the connection.

Similar functions are provided by central equipment in wireless networks, where each wireless device communicates with a base station. The VNet does not use any base station for the communication of local users, while the VNet bridge implements data forwarding functions ~~at higher level~~ for users belonging to different networks. For that reason, the network emulation functions are distributed at the wireless devices and are implemented independently from other modem functions.

Each wireless modem contains a "network emulation" unit which co-operates with the remote wireless modem "network emulation" unit in order to implement the network emulation functions.

The "network emulation" unit supervises the modem operation, responds to externally generated events, initiates network management functions and informs the modem's user about the network status. This unit receives the request to establish a connection with another wireless modem, checks the availability of its own resources, transmits a packet requesting the connection establishment, receives the remote unit response (or detects the absence of any response) and informs the user on the results of its request.

During the data transfer phase, the "network emulation" unit uses the exchanged data to monitor the status of the connection. If no data are exchanged but the connection remains active, the "network emulation" units exchange packets periodically, in order to inform the other side that they are still active and that the connection is still operational. If the "network emulation" units can not communicate, they assume that the other side terminated the connection, and in that case, they release their resources and return the modem into the idle mode of operation. If a wireless modem can not accept a new connection request, it generates a "busy" packet, indicating to the remote side its unavailability to accept a new connection at that time.

The "network emulation" unit is also responsible to negotiate the Quality of Service (QOS) parameters during the connection establishment phase. The QOS parameters determine the format that will be used during the data transmission, the used protocols, the protocol parameters etc. Figure 2 shows the "network emulation" unit state diagram. The *Idle* state is the initial state, where no connection is active and the system is ready to accept a new connection. Whenever the user of the modem requests a connection establishment, the "network emulation" unit enters the *Outgoing Connection Pending* state, until the connection is established or finally rejected. The "network emulation" unit enters the *Incoming Connection Pending* state, when a request for connection is arrived from the network. In that case, the "network emulation" unit determines what QOS parameters can be satisfied, decides on alternative options and finally communicates with the modem's user for the connection acceptance. The *Data Transmission* state is used during data transmission and the "network emulation" unit returns to the *Idle* state whenever the connection is terminated or an unrecoverable communication error is detected.

During data exchange, different protocols can be used for flow control and backward error correction. These protocols are negotiable during the connection set-up. In its simplest version, no error recovery is implemented. In that case, any packet corrupted with noise is discarded by the system, and it is the responsibility of the application software to handle that case. When backward error correction is implemented, the system provides error free transmission links, since more sophisticated retransmission protocols are employed.

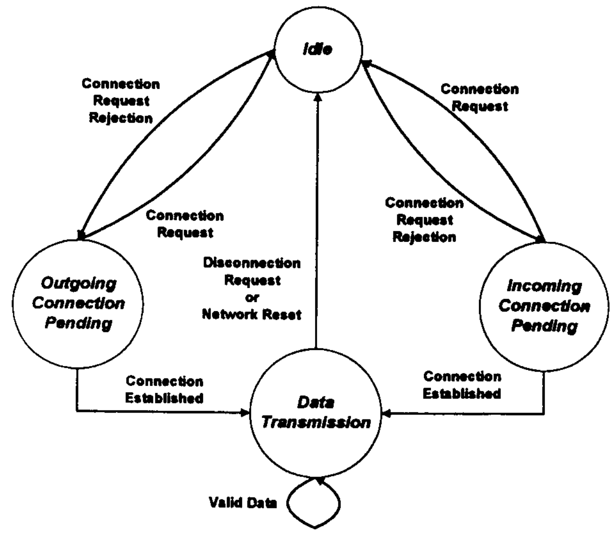

Fig. 2. The "network emulation" unit state diagram

The communication between a computer attached to a wireless modem and another computer attached to a wireline modem is achieved via a VNet bridge. The VNet bridge is used for establishing the wireline segment of that connection. This procedure is shown in Figure 3. The calling user specifies the bridge address as the local address and then the wireline modem address. This is achieved by using standard AT-commands. The wireless modem initially establishes a connection with the wireless modem connected to a port of that bridge. Then it provides to the bridge the telephone number where the wireline modem is connected. The bridge establishes the connection and then a number is allocated to that specific connection. The wireless modem uses that number and the wireless modems addresses to transfer the data. If the bridge detects that an unrecoverable error is met at the wireline segment of that connection, informs the call originator about that and returns to the state where the wireless connection was established, but the wireline connection has not achieved yet. In that case, it is the originators responsibility to either discard the whole connection, or to keep the wireless connection and to try to re-establish the wireline connection. In case the wireless connection is interrupted, the bridge is informed

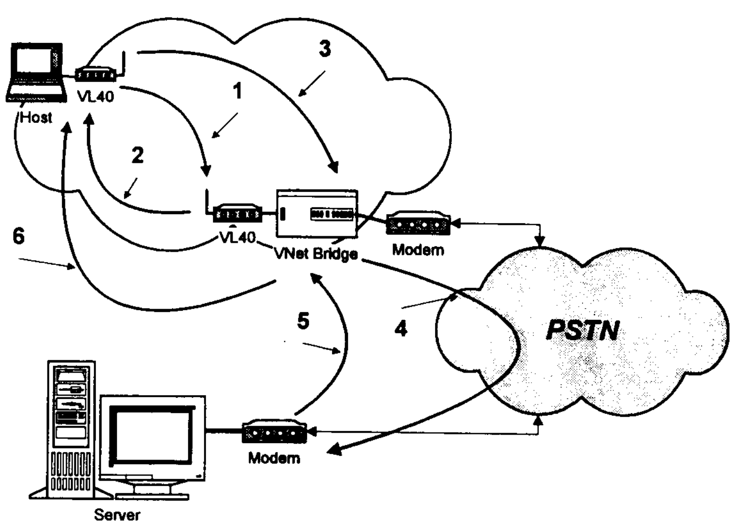

Fig. 3 The connection establishment procedure between a wireless and a wireline modem.

about that and terminates the wireline connection immediately.

In the case where connection between two wireless modems, belonging to different networks attached to different bridges, has to be established, three separate connections have to be done. The complete path is determined by the call originator, and the two intermediate bridges are used for forwarding the original request. The interruption of any of these three connections, forces the system to discard also the other two, and then to release the system resources.

The VNet supports the following communication scenarios:

1. Wireless modems belonging to the same network.
2. Wireless modems belonging to different networks, but to the same bridge.
3. Wireless modems belonging to different networks and to different bridges.
4. Wireless modem and wireline modem.

In order to achieve these networking capabilities, the following addressing scheme is used. Each wireless modem has a user configurable address which is unique in the respective wireless network and becomes unique in the whole network architecture, when it is combined with the local network unique address. The address of each local network is defined by the respective PSTN address (telephone number), where that network is connected, and the bridge port, where that network is attached. Each VNet bridge is able to support of up to eight (8) local wireless networks or wireline connections. Each wireless network may have more than one bridges for interfacing with the PSTN. In case there are two or more alternative routes for interconnecting two end-systems, the user that originates the connection determines the preferred path.

The wireless networks use a network protocol for single, group and broadcasting message delivery. A type of connection oriented data link protocol ensures reliable message delivery with different message types and characteristics. The network management provides diagnostic functions and message authentication. The system provided services are distinguished into three categories: application services, management services and configuration services.

The application services use a set of protocols for supporting widely used applications. These services include connection establishment, file transfer, terminal access etc. and custom configured services, like collection of sensorial data. The management services include security services, medium access and transmission services, while the configuration services include set-up of protocol parameters, testing procedures etc. During connection set-up, protocol dependent parameters are negotiated and thus, reliable, transparent data transfer is achieved.

Although the system is based on connection oriented data transfers, the wireless network uses a multi-access protocol, based on the Carrier Sense Multiple Access (CSMA) protocol, which is upgraded to the connection oriented service by the data link protocol. Each wireless modem supports up to 16 concurrent connections within the same or other networks.

The VNet can easily support protocols, like the Serial Line Interface Protocol (SLIP) and the Point-to-

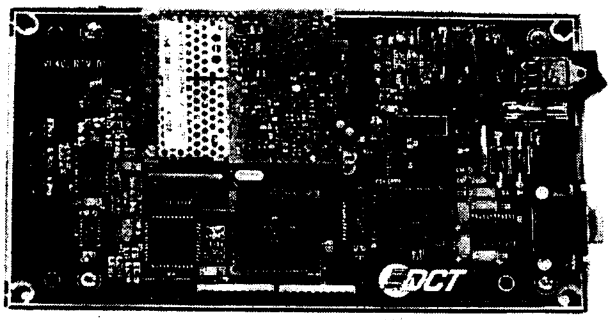

Fig. 4. The VirtuaLink-40 modem

Point Protocol (PPP), thus extending the Internet capabilities to mobile users. The modem accepts PPP frames, segments them on smaller packets, assembles them into radio frames and sends them to the destination modem. The modem at the destination receives the radio frames, disassembles the original packets and, by using the selective retransmission protocol, regenerates the original PPP frames and delivers them to the attached host computer.

4. Modem Architecture

The VirtuaLink-40 wireless modem (shown in Figure 4) uses a powerful microcontroller to execute all communication protocols and a real-time multi-tasking kernel (SOSystem) to handle all timing functions that are related to the protocol state machines. Its baseband section uses a custom packet controller with programmable line coding and a GMSK modem. The transmission speed is 14.4 kbps using 25 kHz channel spacing, although the baseband section can support data rates up to 40 kbps. Figure 5 shows the modem architecture.

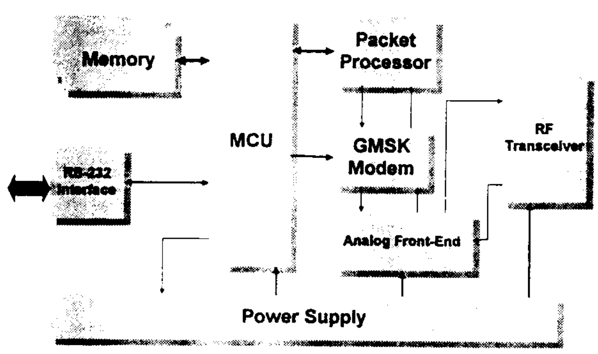

Fig. 5. The wireless modem architecture

The RF transceiver is a half-duplex synthesised module with user programmable carrier frequency and transmission power, operating at the UHF band. Up to 800 different channels can be selected by the modem user. Since the standard AT commands do not support RF transceiver programming, an extended AT commands set is used, that also supports various system functions. Using the extended AT commands set, the packet controller is set-up to support different protocols or different protocol parameters, the "network emulation" unit is configured (remote and local address, timing parameters) and the communication protocol parameters are adjusted.

The VirtuaLink-40 is a synchronous modem, that transmits bursts of data, using a packet controller. The packet controller receives raw data and forms the radio frames. It generates the frame preamble and synchronisation patterns, the appropriate frame fields (addressing, length, control/type indicators, padding etc.), scrambles the data and generates the packet CRC using the CCITT-16 polynomial. The CRC is generated either once per frame, or every k-bytes, where the k value is defined by an extended AT-command. The packet controller implements also the line coding scheme for adjusting the data bandwidth to the RF transceiver bandwidth [8]. The coding scheme is based on DC offset adjustments using bit insertion. During the bit stream transmission, a DC offset measurement circuit is activated. Whenever the DC offset exceeds a predetermined threshold, an inverse polarity bit is inserted, thus adjusting the DC offset value towards 0. The generated bit stream is filtered using a Gaussian filter, thus shaping the output bandwidth according to the RF transceiver bandwidth.

The modem firmware is organised in multiple tasks, co-ordinated by a real-time operating system. The Simplified Operating System (SOSystem [9]) consists of a priority-driven scheduler and three resource managers, the event manager, the memory manager and the time manager. The scheduler supports a limited set of real-time multitasking procedures and a pre-emptive priority driven CPU allocation mechanism. The Event Manager is used for inter-task communication by allocating static buffers and using an ownership control mechanism. The Memory Manager is used for associating parts of the MCU memory map to specific connections. The Time Manager notifies the tasks for the expiration of predetermined time intervals and controls the Connection Supervisor task, which emulates the wire-line signalling and monitors the status of each active connection.

The VirtuaLink-40 firmware is organised in six main tasks that perform the data processing and the network management functions. Figure 6 shows the relations between the various tasks. Their relation with

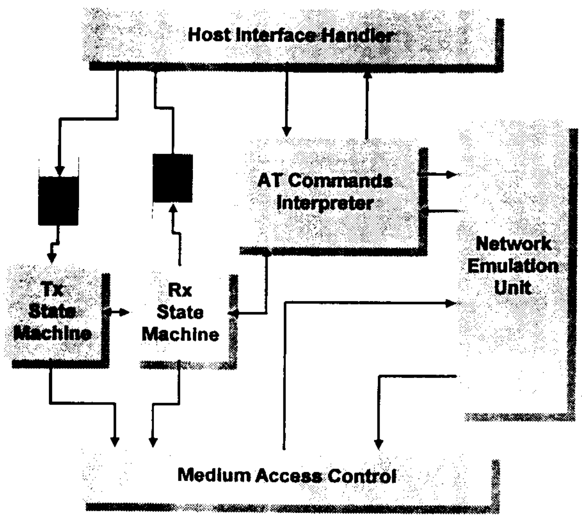

Fig. 6. The firmware tasks.

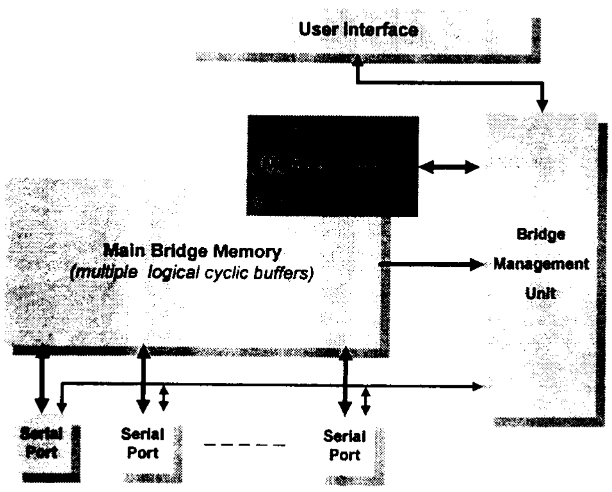

Fig. 7. The VNet bridge functional architecture.

the operating system is not shown for the shake of simplicity. The Medium Access Control (MAC) task controls the RF transceiver and the packet controller and is responsible for frame transmission and reception. Address filtering and multiplexing functions are implemented in this task. The MAC task interfaces with the two protocol state machines and the "network emulation" unit. The data of the "network emulation" unit have always the highest priority. The protocol state machines (one for each direction) implement the user selectable data link layer protocol and are co-ordinated by the "network emulation" unit and the SOS Time Manager. They communicate with the Host Interface Handler using two buffers, where the raw user data are stored. The modem has two modes of operation, the online mode and the programming mode. During the online mode, the AT Command Interpreter is inactive until a 'switch to programming mode' string is received. In that case, the AT Command Interpreter is activated and the Host Interface Handler is disconnected by the two main internal buffers. The AT Command Interpreter is the module that updates the operational parameters of all other modules, using either the latest AT command or the parameters stored in the microcontroller EEPROM.

The following table summarises the basic modem characteristics:

CHARACTERISTIC	*VALUE*
Frequency	450 - 470 MHz
Channel spacing	25 KHz
Available channels	800
Data Buffer	24 Kbytes
Tx ON time	less than 10 msec
Data rate	14400 bps
Host data rate	38400 bps

The VNet bridge has been developed using a powerful PC with multiple serial ports. One of its ports is connected to a wireline modem and another one is connected to a wireless modem. The other six ports are interfaced with either wireline or wireless modems. Each port is controlled by an interrupt driven handler, which forwards the data from/to the main system memory or controls the modem status of operation. Figure 7 highlights the bridge internal structure. The main memory is organised as pairs of logical cyclic buffers, one pair per established connection. Two cyclic buffers are needed for each connection, for transferring the data in each direction. The bridge management unit is used for allocating the system memory to different connections, informing the port handlers for the memory organisation, establishing new connections and releasing the resources of terminated connections. The bridge management unit includes also the required functionality for making decisions on data routing and connections management.

5. Conclusions

The presented VNet system expands the telephone network capability for data exchange to wireless users. This system requires minimum additional hardware for providing the networking functionality and it does not require any modification on the existing application software, since it contains all required functions to emulate the telephone network operation in the wireless environment.

The VNet can be used in various types of applications, like wireless accessing the Internet, remote login, FTP, remote data control and monitoring, etc.

Although it does not have the flexibility of a permanent infrastructure deployment for supporting the wireless nodes, individual network deployments are extremely low-cost and flexible to install. Furthermore, such deployments are not limited by infrastructure coverage such as in the case of cellular wireless data services. Finally, a big advantage of using the VNet is that the cost of a connection between nodes through PSTN is the cost of the PSTN call. Connections that do not use the PSTN, have no fee.

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