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MASTERs 2007

11050 TCP

Hands on with the Microchip TCP/IP Stack (8 hours)

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Class Objective

When you finish this class you will:

- Know of the Microchip Ethernet and Internet networking solutions
- Know of protocols such as HTTP, Telnet, NBNS, SNTP, DNS, DHCP, etc. and their value to your application
- Understand how to modify the Microchip TCP/IP stack to develop your applications

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Agenda

- **Ethernet – Overview**
  - Demo 1 – What's possible
  - Lab 1 – Join the network
- **TCP & UDP**
  - Lab 2 – Peek in with Wireshark
- **ARP & DNS**
- **HTTP2 & MPFS2**
  - Lab 3 – Change variables, form submission, and authentication options
- **Simple Mail Transport Protocol (SMTP)**
  - Lab 4 – Send email to yourself
- **Microchip Bootloader**
- **Other Modules**
  - Lab 5 – Bootloader, Telnet, SNTP, ICMP, DHCP
- **Frequently Asked Questions**

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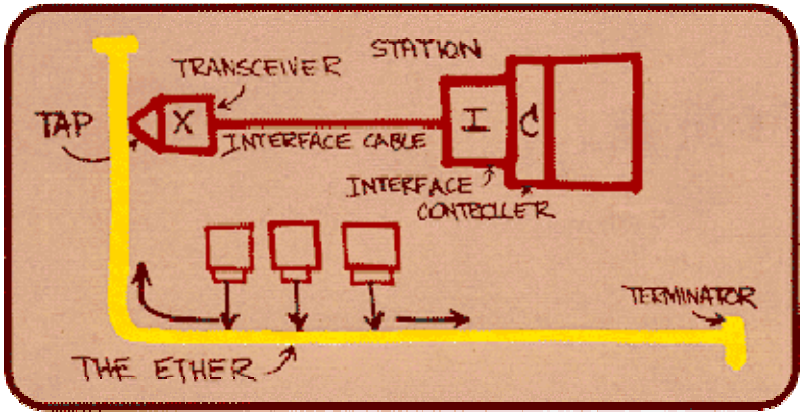
Summary

- Overview of Ethernet products and status
- Wireshark and TCP/IP Stack protocols
- Editing web pages to suit your application
- Experience using SMTP, HTTP2, MPFS2, Telnet, Bootloader, SNTP, and other modules

Ethernet – Overview

Why Ethernet?

- Ethernet is the most widely deployed network in offices and industrial buildings
- Ethernet's infrastructure, interoperability and scalability ensure ease of development
- Once equipment is connected to an Ethernet network, it can be monitored or controlled through the Internet



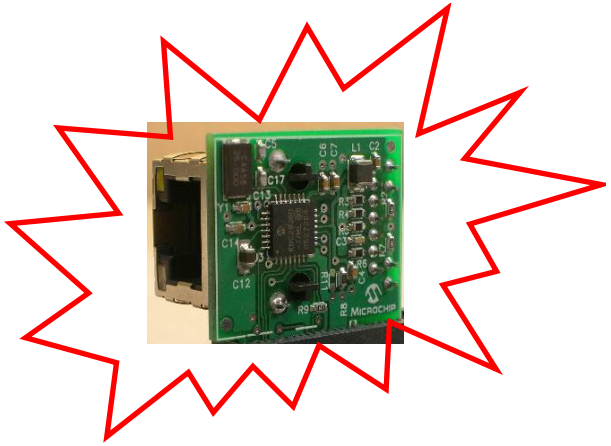
Ethernet Properties

- **Frame based**
  - All packets must be 64 to 1518 bytes long
- **Data is protected from corruption through hardware CRC checking**
- **Hardware usually filters unwanted traffic from arriving at your protocol stack**
  - Ethernet switches/routers do not send packets to you if they are not addressed to you
  - Ethernet controller contains receive hardware filters
- **Ethernet provides best effort transmission**
  - Packets that cannot be delivered or are damaged in transmit are thrown away, requiring application intervention

What can I do?

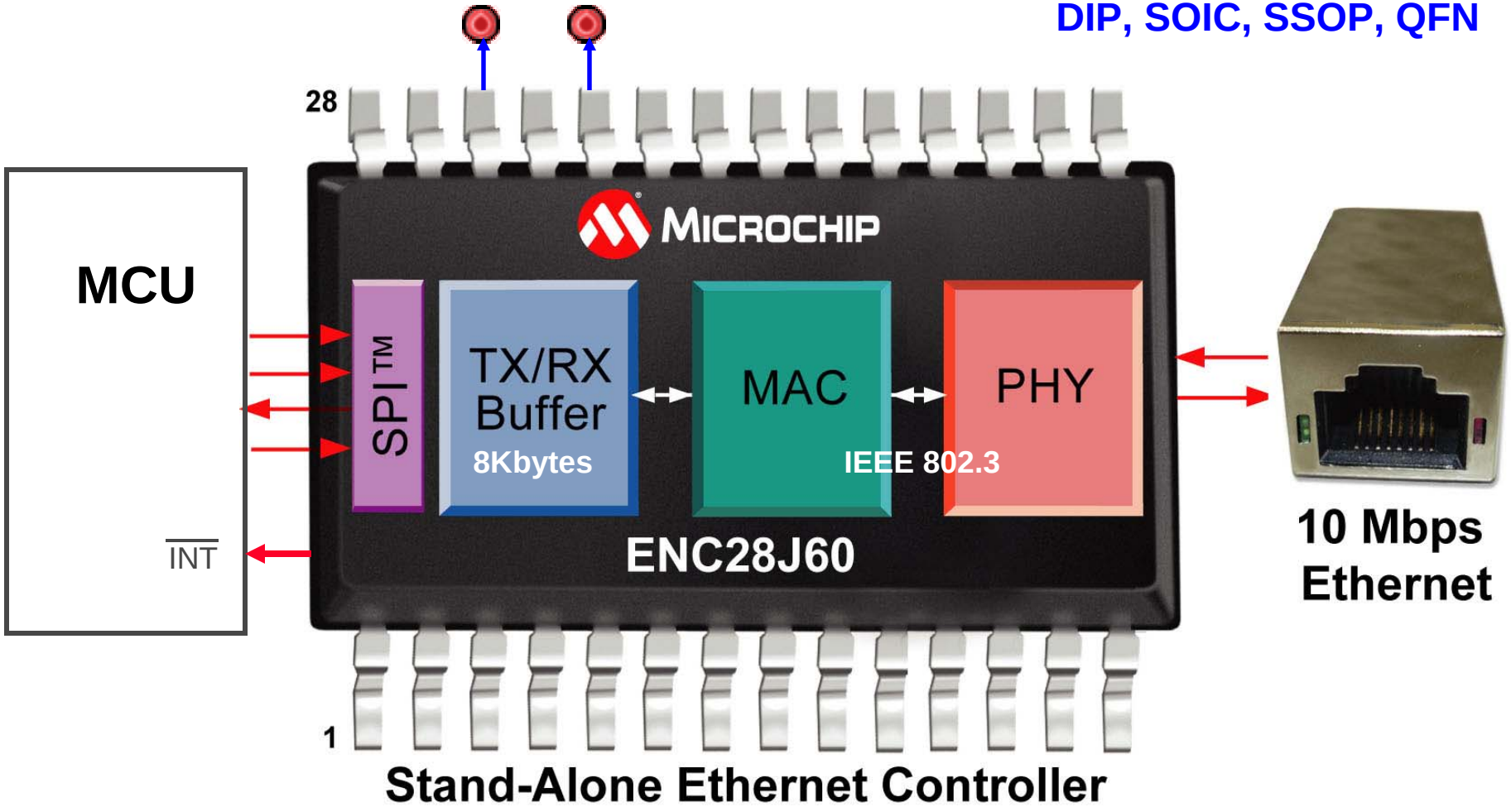
Provides Remote Application Access

Demo 1



- **Some possibilities…**
  - A stand alone Internet MP3 radio
  - On demand status and control system
  - Legacy RS232/Serial to Internet bridge

ENC28J60 Ethernet Controller



PIC18F97J60 Family PIC® MCU with Integrated Ethernet

- PIC18F97J60
  - 64K, 96K or 128K bytes Flash
  - 3.8K bytes RAM
  - 8K bytes TX/RX Buffer
  - 41.667 MHz max @ 3.3V
- Package (TQFP)
  - 64/80/100-Pins
- Other:
  - External Memory Bus
  - 16 channel 100ksps 10-bit A/D
- Communication
  - Ethernet: MAC+PHY (IEEE 802.3 10BASE-T)
  - 2 EUSARTs
  - 2 MSSP (SPI /MI^{2}C)

Silicon Products

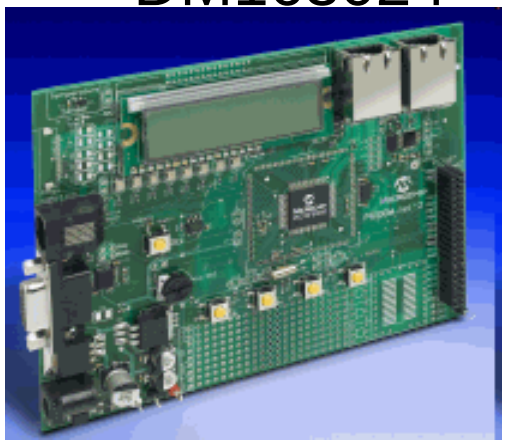
- **ENC28J60 – In production**
  - Stand-alone 10BaseT with 20MHz SPI
  - 3.3V, 8KB RAM
  - 28-pin SOIC, SSOP, QFN, SPDIP
- **PIC18F97J60 family – In production**
  - Integrated PIC18, features similar to PIC18F87J10 + ENC28J60 memory mapped
  - 3.3V, 64-128K flash, 3.8KB + 8KB RAM
  - 64, 80, or 100-pin TQFP
- **ENC624J600 family – Under development**
  - Stand alone 10/100 with ~20MHz SPI or ~20MHz 8/16 parallel bus interface
  - 28-pin SOIC, QFN, SPDIP and 44, 64-pin TQFP

External Components For Ethernet Solution

- 25MHz 50ppm crystal
- Ethernet transformer module
- RJ45 jack
- ~11 resistors
- ~10 capacitors
- 1 ferrite bead
- Unique MAC address
- 3.3V 200mA power supply

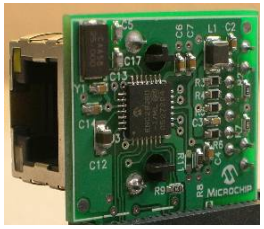
Boards

PICDEM™.net 2
-DM163024



Ethernet PICtail™
-AC164121

Ethernet PICtail™
Plus
-AC164123

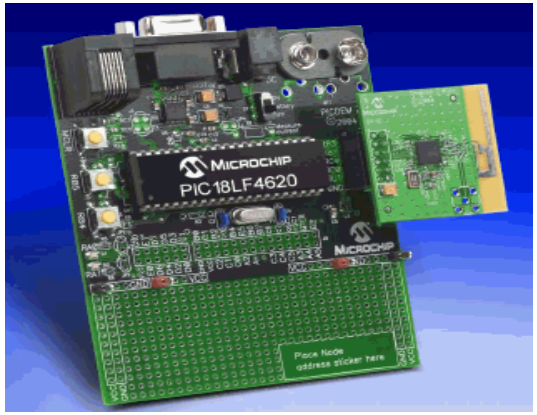


Ethernet PICtail™ Supporting Demo Boards

PICDEM™ HPC Explorer Board (DM183022)

Recommended due to 128KB Flash size

PICDEM Z Board (AC163027-1)

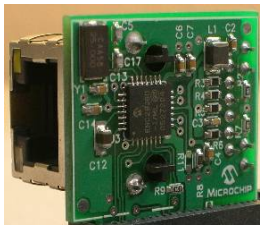


Ethernet PICtail™ Daughter Board

Others (dsPICDEM™ 1.1, etc)
- Requires air-wiring to PICtail connector

Ethernet PICtail™ Plus Supporting Demo Board

Explorer 16
(DM240001)



Ethernet PICtail™ Plus
Daughter Board

Stack Software

- **Version 3.75 and below**
  - Obsolete, strongly encourage updating
- **Version 4.02, 4.10 and above**
  - 4.10 is latest available
  - Many, many improvements and robustness enhancements from years past
  - Includes TCP, UDP, DHCP, DNS, HTTP, FTP, Telnet, NBNS, ICMP, SNTP, SNMP, SMTP, UART bridging, and more

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Lab 1

- **Join our network**
  - Program your board with a unique MAC address and hostname
  - Edit MY_DEFAULT_MAC_BYTE# in `TCPIPConfig.h`.
  - Edit MY_DEFAULT_HOST_NAME in `TCPIPConfig.h`.
- **Upload web pages to the board**
  - Use MPFS2.exe
- **Access the board using the hostname, ex: http://mchpboard/**

Microchip's TCP/IP Stack

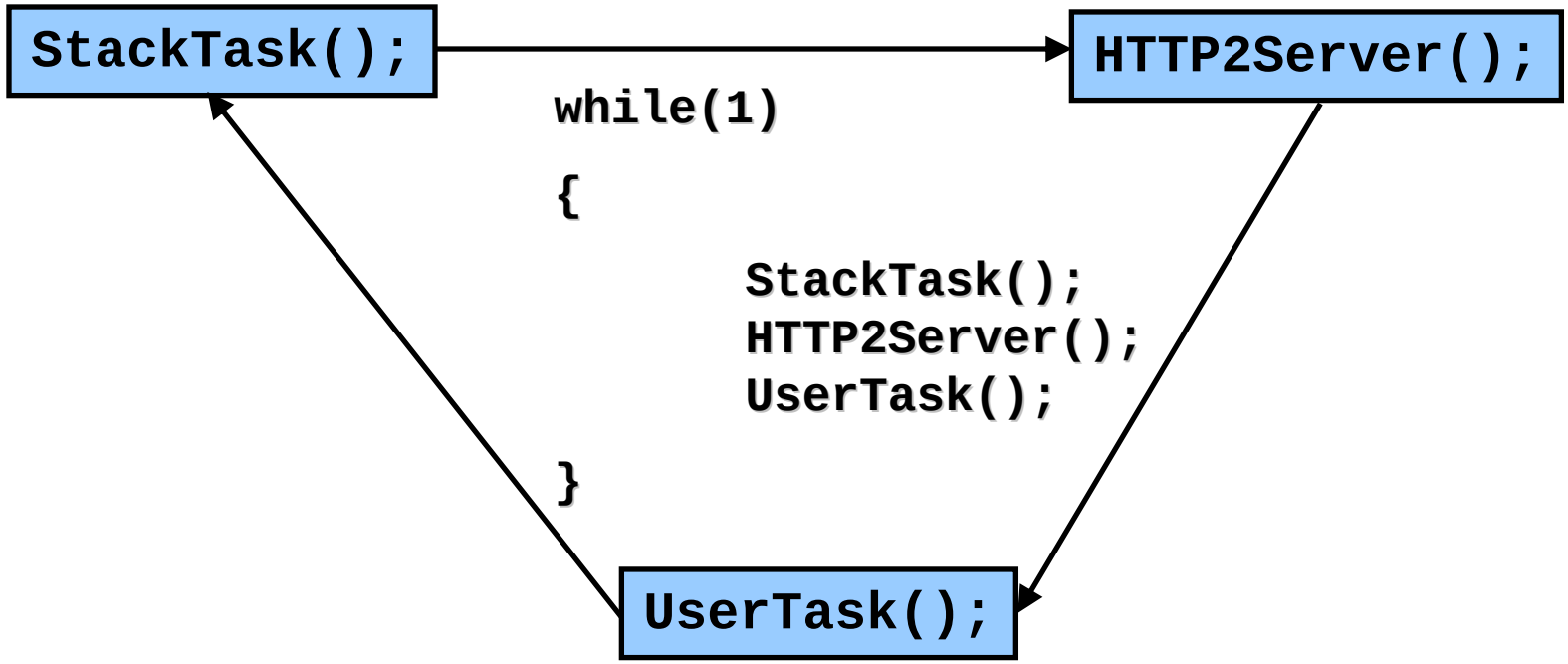
Microchip's TCP/IP Stack

- **Microchip App Note AN833 & AN870**
- **Source code available for free**
  - No fee license agreement
  - Must use with Microchip PIC® MCU or dsPIC® DSC
  - Download off Microchip website
- **Standard Microchip technical support**
- **Suite of files**
  - 'C' Source files and PC based utilities

TCP/IP Stack Features

- **Out-of-box support for Microchip MPLAB® C18, C30, and HI-TECH PICC-18 compilers**
  - Supports PIC18, PIC24F, PIC24H, dsPIC30F, and dsPIC33F processors
- **RTOS independent – Cooperative Multitasking Environment**
- **Modular Design**
  - All big features can be selectively removed by commenting out a single line
  - Implements full TCP state machine
  - Multiple socket support for TCP and UDP

Round Robin Task Switching



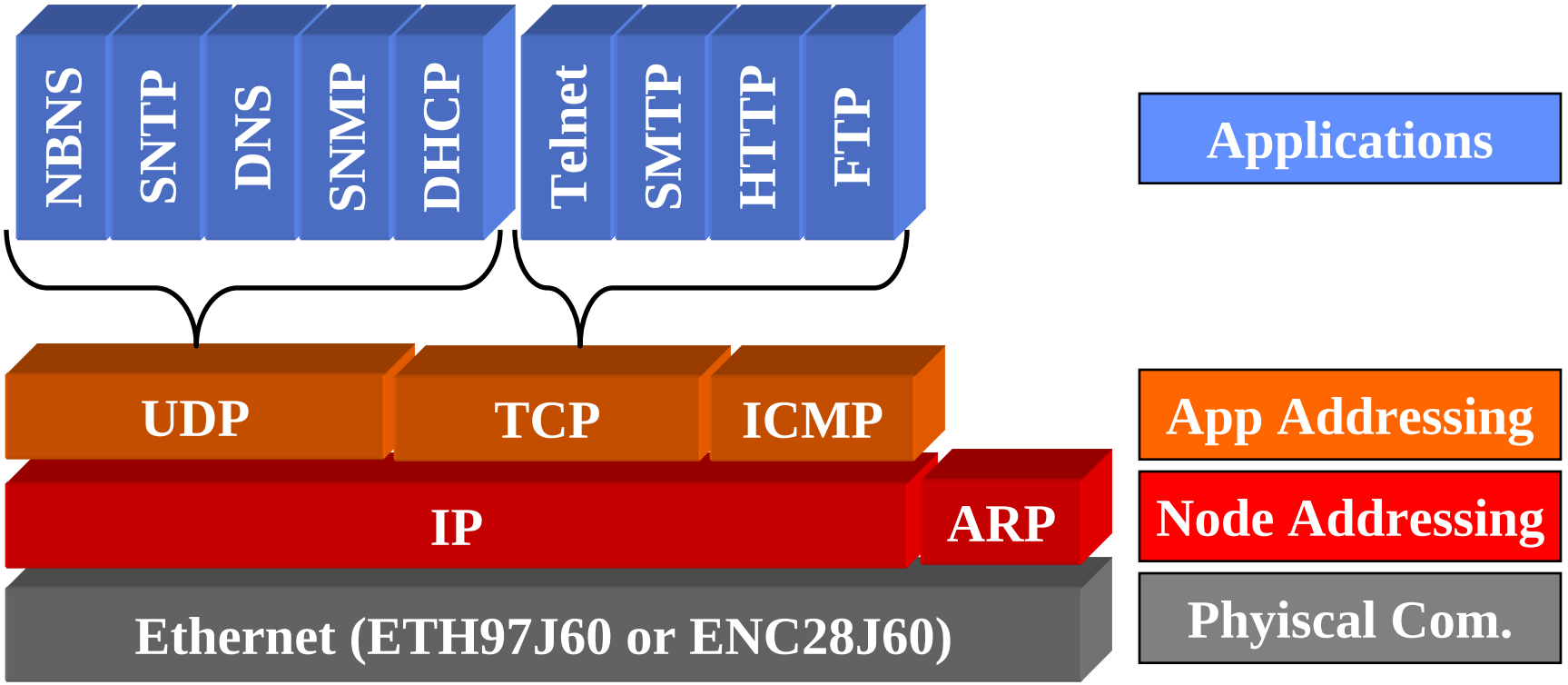
Cooperative Multitasking

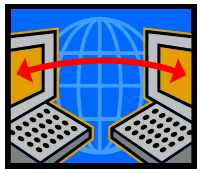
- **No task can block the processor**
  - Blocking will prevent stack from processing packets, lowering throughput
- **Break up long jobs into small chunks**
- **Use a state machine to keep track of position in UserTask()**
- **If nothing to do in UserTask(), return the extra cycles to the stack**

TCP and UDP

Stack Layers

Internet Protocol Stack





User Datagram Protocol (UDP)

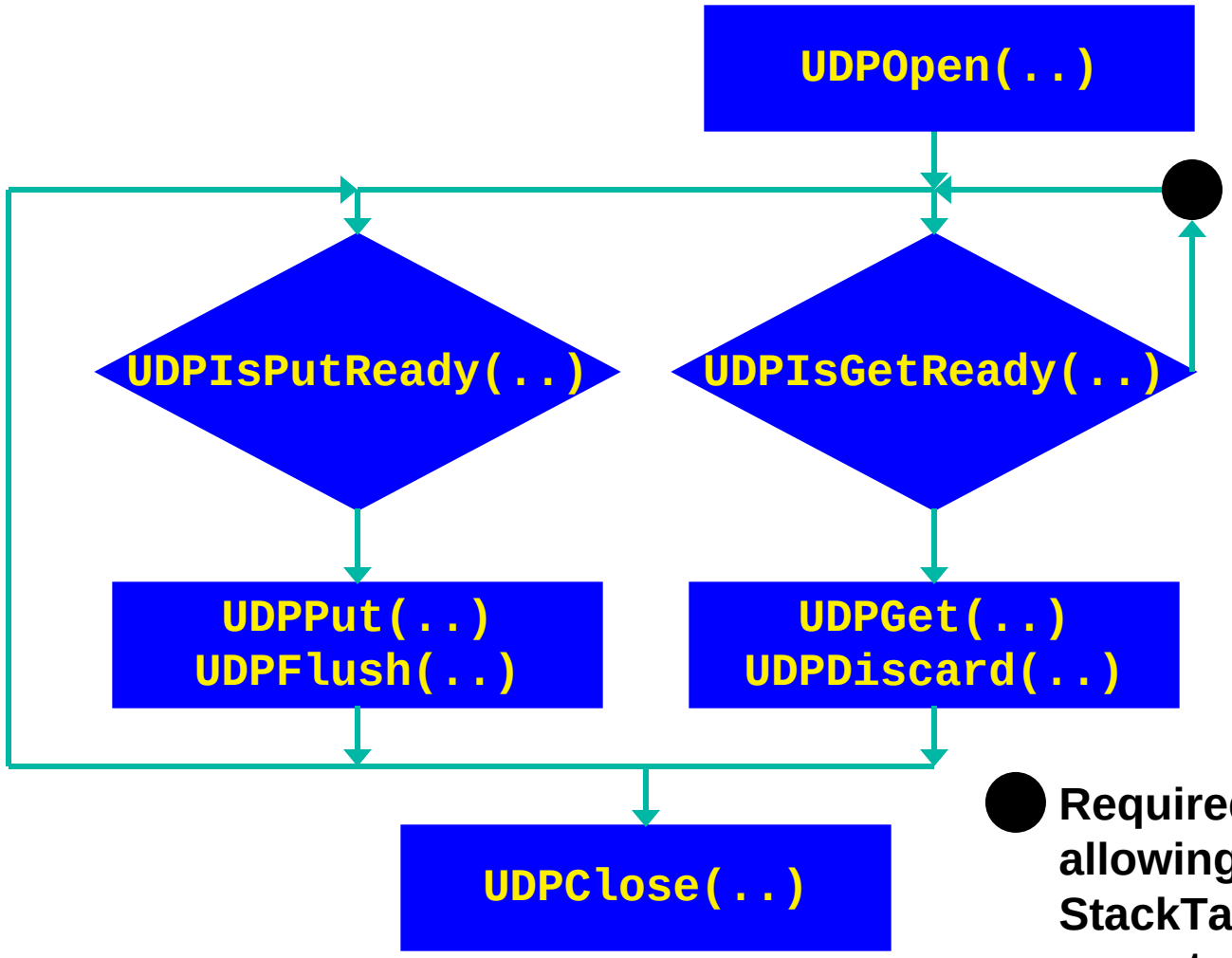
- **Provides high performance but unreliable communication to applications**
  - No connection set up overhead
  - Out-of-order, duplicate, and corrupted frames may arrive at application
  - Frames may get lost
  - Single packets can be multicasted or broadcasted to multiple nodes

User Datagram Protocol (UDP)

- **Datagram based**
  - Data sent from one application arrives at the destination application in a defined packet
  - Maximum recommended size is 512 bytes of application data

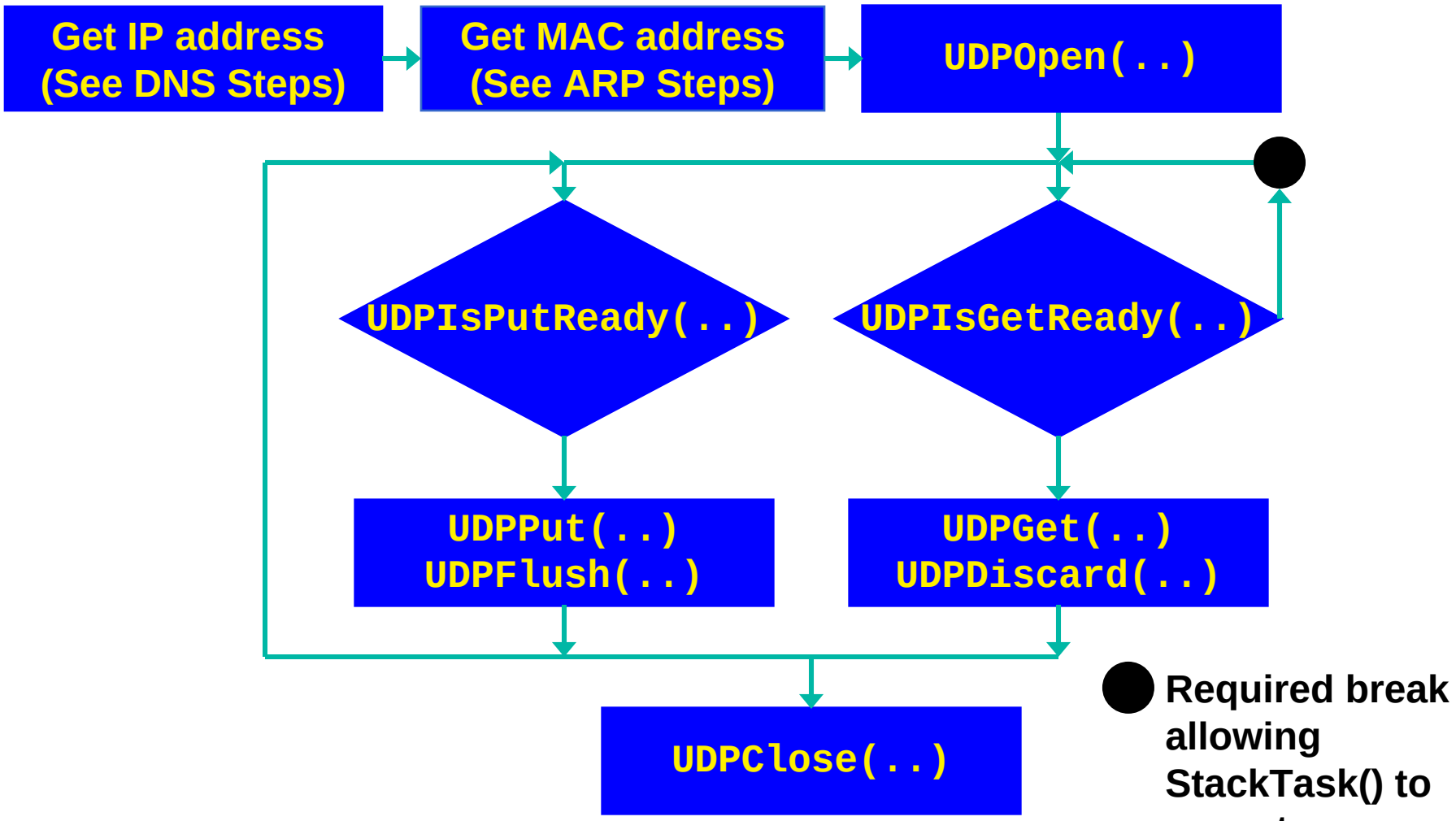
- **Microchip stack does not save UDP packets between task times**
  - Must save packet if needed later
  - Must build and transmit packets in one task time

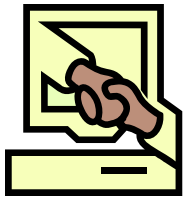
UDP Server Steps



● Required break allowing StackTask() to execute

UDP Client Steps





Transmission Control Protocol (TCP)

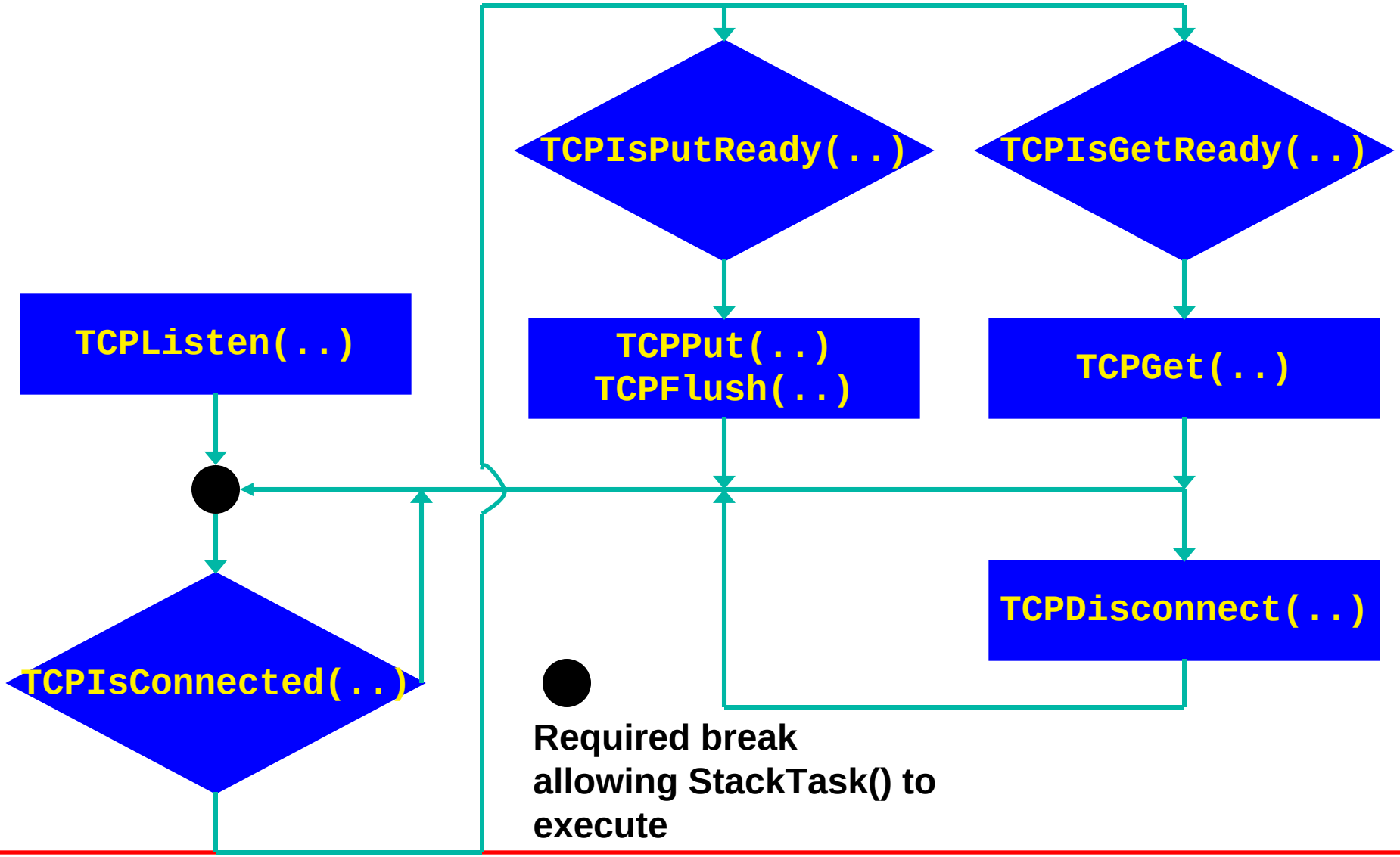
- **Provides reliable communication to applications**
  - Must establish a 1-to-1 connection to talk and receive
  - All data is acknowledged
  - Corrupted/lost data is automatically retransmitted
  - Duplicated data is discarded
  - Out-of-order segments are placed in correct order
  - Automatic flow control

Transmission Control Protocol (TCP)

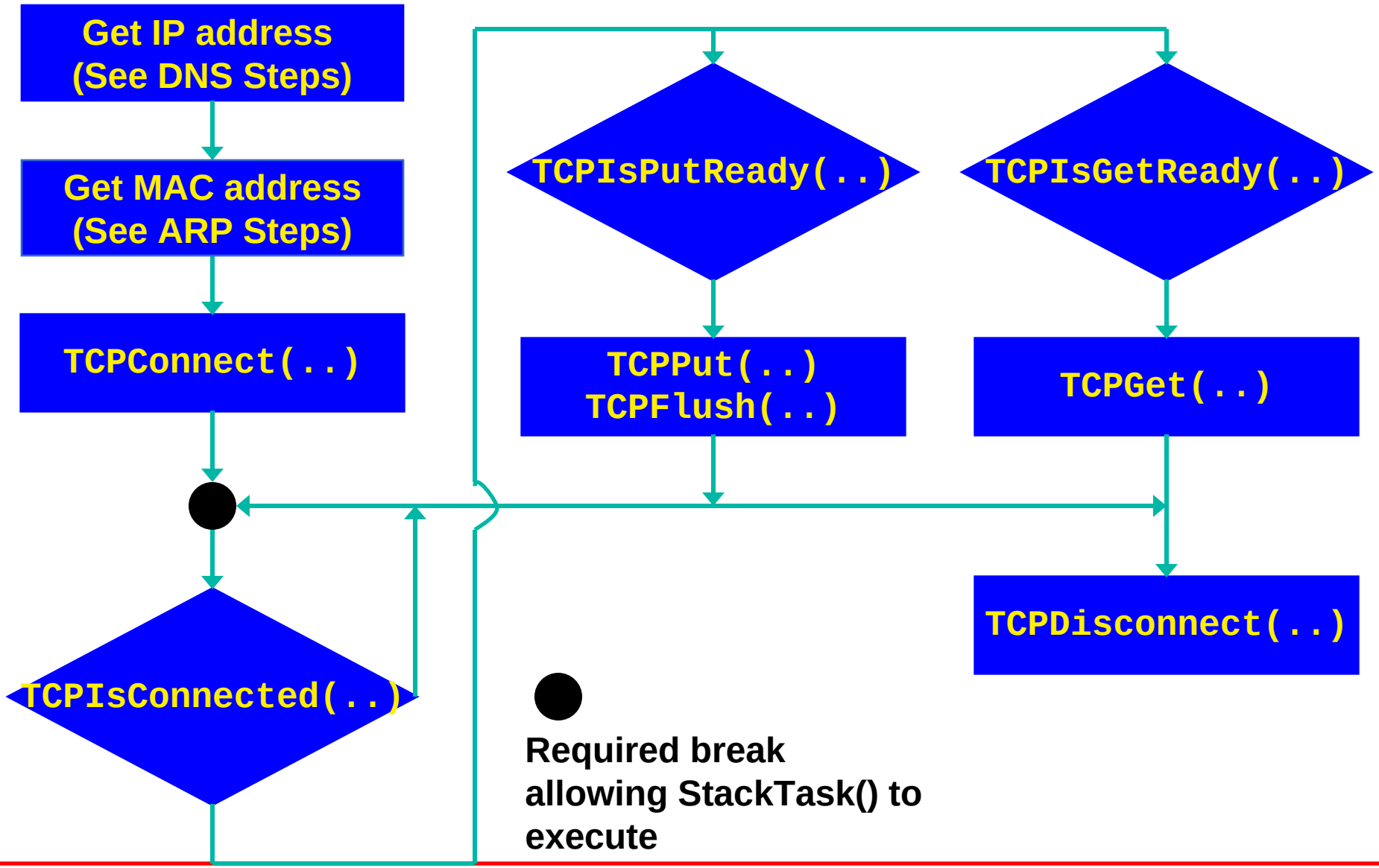
- **Stream based**

  - Routers may fragment/combine packets at random
  - Two adjacent application data bytes may arrive in two separate Ethernet packets at the destination
- **Microchip stack saves all TX & RX data for each application between task times**
  - Each socket gets its own FIFO buffers for transmitting and receiving
  - Performance drops substantially with increased round trip acknowledgement latency

TCP Server Steps



TCP Client Steps



Take a look at it all

- **Wireshark captures and decodes Ethernet frames**
  - Free (GNU GPL license)
  - Multiplatform
  - Very large number of protocols and filters supported
  - Download from: http://www.wireshark.org/
  - Formerly called Ethereal

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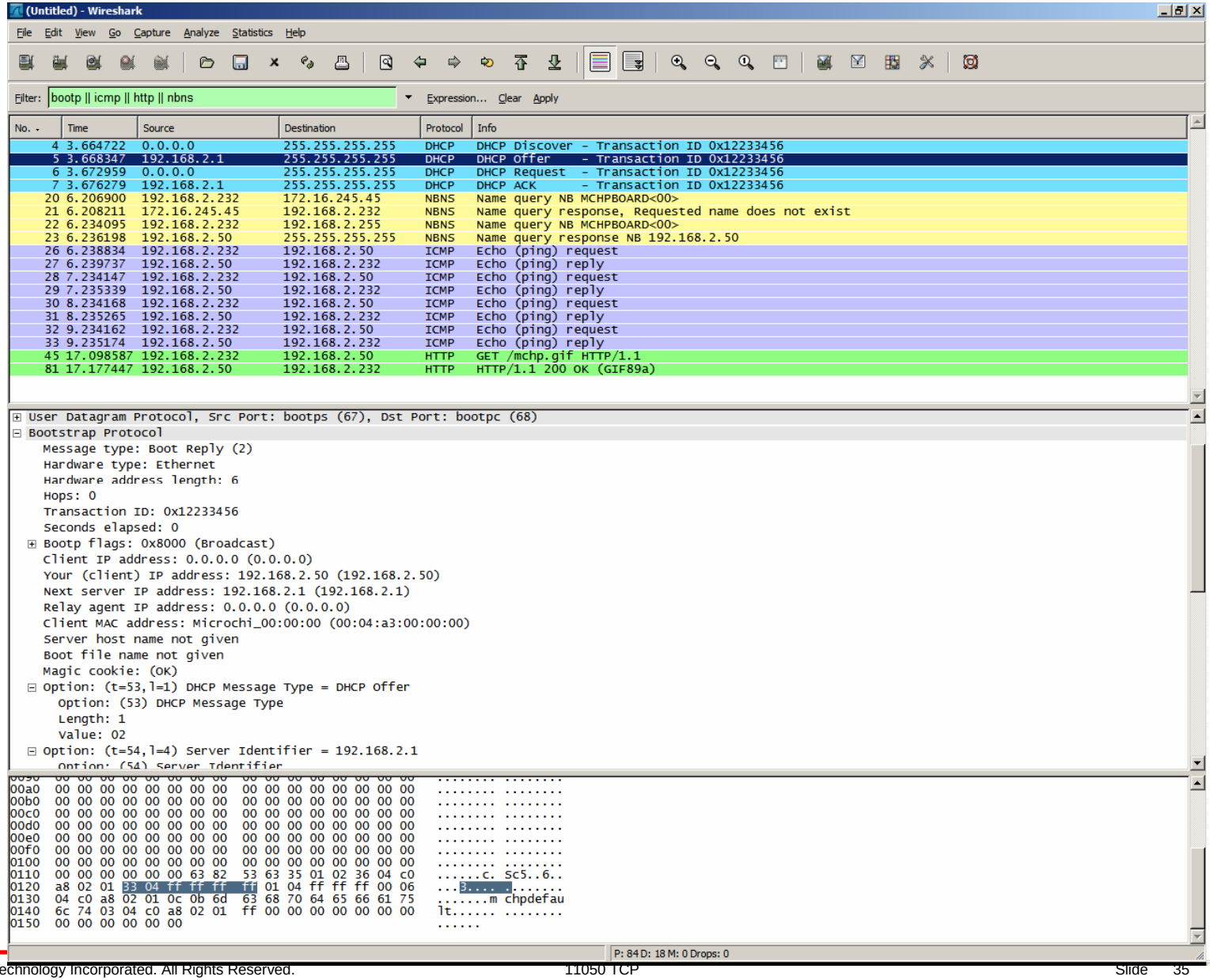
Wireshark



Wireshark

- **Hide unwanted traffic using proper filter:**
  - ip.addr == 192.168.2.101
    arp.dst.proto_ipv4 == 192.168.2.101 ||
    arp.src.proto_ipv4 == 192.168.2.101
- **Use the Expression builder to learn how to filter using other protocol fields**

Lab 2

- **Peek in with Wireshark:**
  - Get your PICDEM.net™ 2 up and serving web pages
  - Capture all traffic between your PC and board
  - Filter out junk traffic on the network
  - Right click and follow TCP stream to observe application communications
  - Find key pieces of information:
    - **PC's MAC address**
    - **Measure time it takes to download mchp.gif**
    - **Figure out what DHCP lease is obtained after reset without looking at LCD**

Address Resolution Protocol (ARP)

Address Resolution Protocol (ARP)

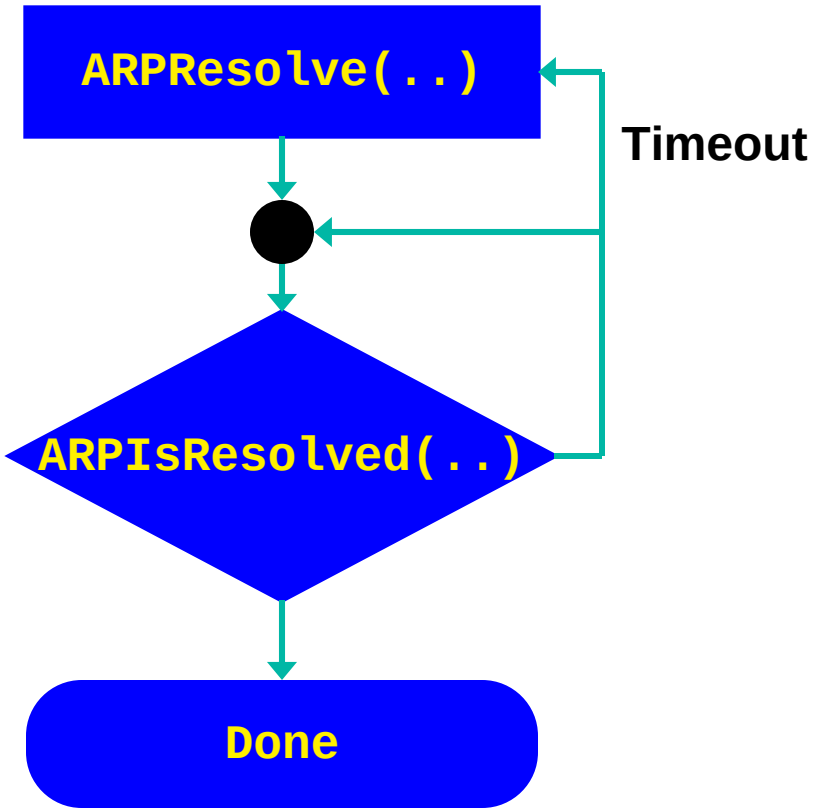
- **Translates IP addresses to MAC addresses**
  - Exposes API to IP or application protocol
  - Broadcast based
    - Broadcast: "Who has 192.168.1.123?"
    - Unicast reply: "I have 192.168.1.123 ; My MAC address is 00:12:34:00:00:01"
- **Required for Ethernet and 802.11 networks only**
  - PPP/serial links do not use MAC addresses

ARP Functions

- **Note: ARP functions may be unneeded in future stack versions**
  - IP address to MAC address translation can be done internally in the TCP and UDP modules so the application won't have to

- **ARPInit**
- **ARPProcess**
- **ARPResolve(…)**
- **ARPIsResolved(…)**

ARP Client Steps



● Required break allowing StackTask() to execute

Domain Name System (DNS)

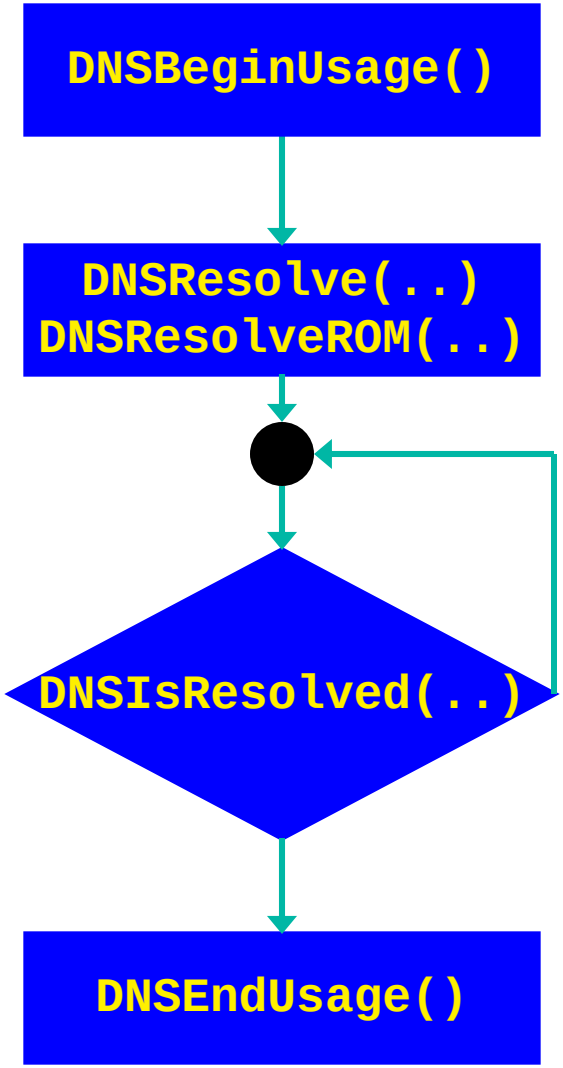
What is DNS?

- **Provides fully qualified host name to IP address translation**
  - Ex: "www.microchip.com" to 198.175.253.32
- **Provides addresses of SMTP servers associated with email addresses**
  - Ex: "support@microchip.com" to mx.microchip.com
- **Stack supports DNS client only**
- **Client automatically finds DNS servers via DHCP**

DNS Functions

- DNSBeginUsage
- DNSResolve(…)
- DNSResolveROM(…)
- DNSIsResolved(…)
- DNSEndUsage

DNS Steps



- Required break allowing StackTask() to execute

HTTP2 & MPFS2

HTTP2 Server

- Multiple simultaneous connections
- Supports HTML Forms
- Supports HTTP GET and POST commands
- Supports Cookies
- Supports Authentication
- Dynamic web page creation
- Pages stored in Program Memory or external non-volatile memory with MPFS2

Dynamic Variables

- **Escape sequence used to do dynamic substitution**
  - 1. Web browser requests `index.htm`
  - 2. Server begins transmitting `index.htm` to browser
  - 3. Each *~variable~* sequence encountered causes HTTP2 callback function in stack to execute
  - 4. Application returns dynamic values to browser in place of *~variable~*
  - 5. Remainder of `index.htm` is sent to browser

Dynamic Variables

- **~variable~ tags specify a file**
  - Ex: `~inc:header.inc~`
  - Whole file will automatically get returned to browser
  - Useful for applying global styles to all pages
- **Non-filename variables cause code to execute:**
  - Ex: ~myVariable~
  - HTTP2 server will call HTTPPrint_myVariable() when ~myVariable~ is reached while transmitting `index.htm`
- **Variables are pre-parsed at MPFS generation**
  - Improves performance

Form Submission

- **Browser form submission executes callback**
  - HTTPExecuteGet() for GET method
  - HTTPExecutePost() for POST method
- **Parameters available in myConn->data parameter**
- **HTTPGet[ROM]Arg() can help parsing**

Form Submission Example

- **1. Browser issues:**
  - GET /forms.htm?led1=0&led2=1 HTTP1.1
- **2. HTTPExecuteGet() executes**
  - myConn->data contains "led1\00\0led2\01\0"
- **3. User code calls HTTPGetROMArg() to obtain value associated with led1**
  - User code sets LED1 I/O pin to value to off
- **4. User code calls HTTPGetROMArg() to obtain value associated with led2**
  - User code sets LED2 I/O pin to value to on

Authentication

- **All files that start with a certain character require username and password**
  - Default character is ‘x’
- **Example**
  - `xSecurePage.htm` is protected
  - `InsecurePage.htm` is not protected
- **HTTPAuthenticate() callback specifies proper username(s) and password(s)**

HTTP2 Functions

Server Implemented

- HTTPInit
- HTTPServer
- HTTPGet[ROM]Arg
- HTTPURLDecode

User Implemented

- HTTPPrint_*
- HTTPExecuteGet()
- HTTPExecutePost()

Web Page Design Guidance

- **Hand-code the pages**
  - Or use appropriate visual web authoring tool
  - Microsoft® Visual Web Developer Express Edition™ is free and potentially suitable
- **Try to shrink the graphics**
  - Use correct file formats
  - **PNG** and **GIF** are usually smaller than **JPG** for images in embedded devices
- **Auto refresh dynamic content only**

MPFS2

- **Provides uniform file retrieval between internal program memory or external SPI EEPROM/Flash**
  - External SPI EEPROM can be updated through MPFS2.exe PC GUI tool
  - Internal program memory is updated by recompiling project and programming
- **PC GUI tool source code available for rebranding and distribution with your application**
  - Still must use PIC® microcontroller

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Lab 3 – HTTP2

- **Use MPFS2.exe tool**
- **Add extra LED output to `dynvars.htm`**
  - Update `CustomHTTPApp.c`
- **Add extra LED form input to `forms.htm`**
  - Update `CustomHTTPApp.c`
- **Update authentication credentials and password protect `upload.htm`**
  - Update `CustomHTTPApp.c`

Simple Mail Transfer Protocol (SMTP)

What is SMTP?

- **Provides ability to transmit Internet email messages**
  - Can be sent to cell phone via SMS bridging
- **Microchip TCP/IP stack implements an SMTP client only**
  - Embedded device can send email, not receive it
  - Receiving mail requires other protocols, ex: POP3 or IMAP

SMTP Client

- **Message headers in ROM or RAM**
- **Message body in RAM or created on-the-fly**
- **Requires about 5 KBytes of ROM, 100 bytes of RAM**
- **Uses external SMTP server (proxy), or**
  - Can try to send emails directly to the destination mail server by doing a Mail eXchanger (MX) record look-up in the DNS.
- **Supports authentication (clear text)**

SMTP Functions

- **SMTPClient Structure**
  - Server
  - Username
  - Password
  - To, CC, BCC
  - From
  - Subject
  - Body
- **SMTPBeginUsage**
- **SMTPEndUsage**
- **SMTPSendMail**
- **SMTPIsBusy**
- **SMTPIsPutReady**
- **SMTPPut(…)**
- **SMTPPut[ROM]Array(…)**
- **SMTPPut[ROM]String(…)**
- **SMTPFlush**
- **SMTPPutDone**
- **SMTPTask**

SMTP Steps

- See `SMTP Application Flow.pdf` in Microchip Solutions\Microchip\TCPIP Stack

Lab 4 – Send email to yourself

- **Goal:**
  - Send yourself two emails, one containing the state of the buttons (in RAM), and one containing the state of the PIC® MCU's RAM.
  - See lab handout for required SMTP server

Internet Bootloader

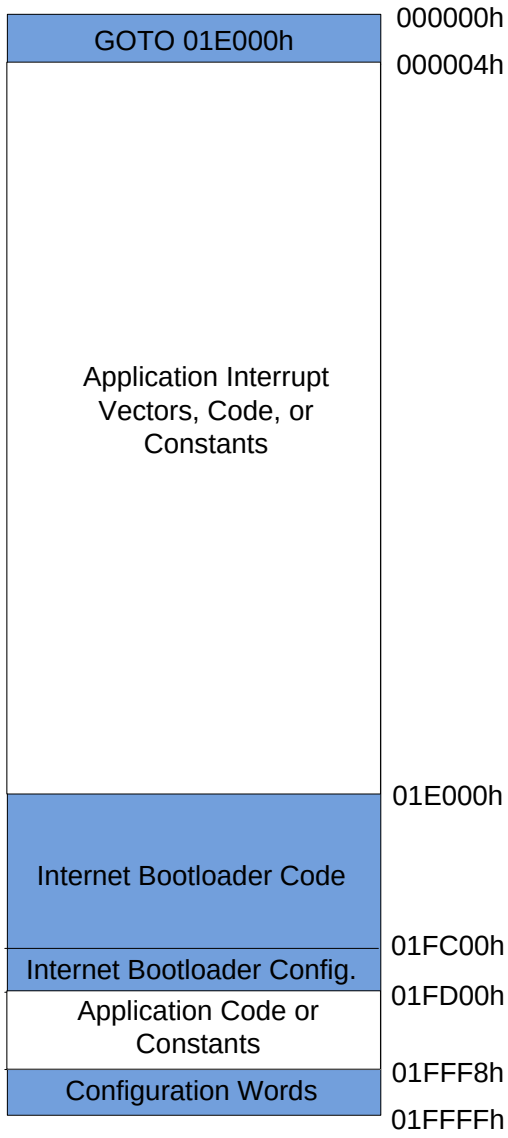
Bootloader

- **Implements its own private UDP/IP stack**
  - 8 KB of Flash on PIC18F97J60 family
- **Executes on Power-on Reset**
  - Waits 3 seconds before starting main application
  - Bootloader packets arriving within the 3 second window can begin reading and writing to program memory
- **Updates configuration fuses**

Bootloader

- **Does not modify interrupt vectors**
- **Executes outside application**
  - Effectively uses no RAM
- **Very easy to link application**
- **PC GUI interface with source code provided**
  - DLL also available for raw reading and writing to addresses without a GUI

Bootloader Memory Map



Bootloader

- **Limitations**
  - Bootloader cannot update itself
  - Cannot use watchdog timer postscalars of 1:1 and 1:2 unless enabled via firmware
  - Bootloader forces HS or HS+PLL clock mode to prevent loss of bootloader clock

Dynamic Host Configuration Protocol (DHCP)

What is DHCP?

- **Provides nodes with IP address, subnet mask, gateway address, DNS server addresses, and other configuration parameters**
- **Supports full DHCP client**
  - Updates `AppConfig` structure
- **Supports single node DHCP server**

DHCP Server

- **Allows one client**
  - Useful for direct connection to PC or second embedded device
  - Operates simultaneously with DHCP client
- **Automatically disables itself if the DHCP client successfully contacts a different DHCP server**
- **Gives a lease of only 15 seconds**
  - Forces client to constantly renew
  - Prevents IP address from staying in use if authoritative DHCP server is present

NetBIOS Name Service (NBNS)

What is NBNS?

- **Provides host name to IP address translation**
  - Ex: “mchpboard” to 192.168.2.100
- **Limitations**
  - Only works on a single broadcast domain (same subnet)
  - Supports up to 15 characters

NBNS Functions

- **NBNSTask**
  - Operates as a passive server, listening for broadcasts
  - Replies to name queries only
  - Does not generate name queries
  - `MY_DEFAULT_HOST_NAME` is the only configuration option

Simple Network Time Protocol (SNTP)

What is SNTP?

- **Automatically find current date/time from Internet**
- **Many free servers available**
  - No configuration needed (**pool.ntp.org**)
- **Returns time as 64-bit integer**
  - High order 32 bits specify seconds since midnight January 1st 1970 (or other epoch)
  - Low order 32 bits are fractional seconds (233ps resolution)

SNTP Functions

- **SNTPGetUTCSeconds**
  - Warning: do not use for time difference calculations as date could go backwards on next SNTP update
  - Use **TickGet*()** API for higher than 1 second resolution and difference calculations
- **SNTPClient**

Other Modules

Tick

- **Provides accurate time keeping for non-blocking wait loops**
  - Instead of:
    - **while(i++ < 10000);**
  - Use:
    - **if(TickGet() – i < TICK_SECOND)**
      return;
- **Can be used as a real time clock**
  - Ticks increment on integer multiple of timer hardware input clocks

Telnet Server

- **Text based console interface**
  - Like web browsers, has ubiquitous implementations on PCs
  - Smaller than HTTP2 with MPFS2 for simple command and control
  - Optional authentication is done in clear text
- **Try executing URL:**
  - telnet://mchpboard/

SNMP Agent (Server)

- **Simple Network Management Protocol (SNMP) version 1 supported**
  - Implements traps
- **See AN870**
- **Example SNMP applications:**
  - Cable Modem
  - Network Printer
  - Routers
  - Uninterruptible Power Supply

UART 2 TCP Bridge (Server)

- **Copies data from a hardware UART module to TCP socket and visa versa**
- **UART interface implemented as high priority Interrupt Service Routine**
  - Full duplex at maximum performance
- **TCP interface implemented as cooperative state machine**

Announce (Server)

- Listens for UDP discovery requests from the Microchip Ethernet Discoverer PC tool
- Useful for finding the IP address of your board with DHCP
- Full Microsoft C# source code to PC tool provided
- Demonstrates UDP broadcasting

Generic TCP Client

- **Acts as an HTTP client**
  - Resolves IP address for www.google.com
  - Resolves MAC address for gateway
  - Opens a TCP client socket
  - Downloads Google Search page of "Microchip"
  - Outputs results on UART

Generic TCP Server

- **Acts as a ToUpper() server**
  - Converts each ‘a-z’ character to upprcase ‘A-Z’ and echos it back
  - Other characters echoed back as is

Lab 5 – misc.

- **Program using Bootloader**
- **Try using Telnet, SNTP, ICMP client and server, and DHCP server modules**
  - See handout

Frequently Asked Questions

Notes on security

- **SSL/TLS is coming**
  - Secures HTTP and SMTP modules
  - Will take a lot of RAM and ROM
  - Will take several seconds per connection on PIC18 devices
- **Custom applications with symmetric-only encryption may be more appropriate**
  - See AN953 and AN1044 for strong AES encryption code
- **Secure authentication can be done without encryption**
  - Use secure one-way hash (ex: MD5, SHA1) algorithms to perform a challenge-response
- **Keep your devices behind firewalls whenever possible**
  - If access over Internet needed, use a VPN

Questions

- **How fast is the stack?**
  - See TCPIP Stack Version.txt release notes
  - TCP max TX rate, ~1.4Mbps on PIC24H @ 40 MIPS
    - **Performance drops over Internet**
  - UDP max TX rate, ~3.1Mbps on PIC24H @ 40 MIPS

Questions

- **How big is the stack?**
  - >90 kbytes for all modules, debug optimization
  - >64 kbytes for all modules, full optimization
  - <20 kbytes for minimal UDP only stack, debug optimization
  - Stack is very modular so it depends on application
  - See compiler linker map file for your specific configuration

Wrap Up

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Summary

- Overview of Ethernet products and status
- Wireshark and TCP/IP Stack protocols
- Editing web pages to suit your application
- Experienced using SMTP, HTTP2, MPFS2, Telnet, Bootloader, SNTP, and other modules

Resources

- AN833 – The Microchip TCP/IP stack
- Microchip TCP/IP and Ethernet forum – http://forum.microchip.com/tt.aspx?forumid=173
- Direct Questions – http://support.microchip.com/

Tools Used In This Class

- **Microchip TCP/IP stack**
  - Download from http://www.microchip.com/tcpip
- **MPLAB® IDE and MPLAB C18 compiler**
  - Download from http://www.microchip.com
- **Wireshark network packet sniffer and protocol analyzer**
  - Download from http://www.wireshark.org
- **Microsoft Visual Web Developer Express Edition**
  - Download from http://msdn.microsoft.com/vstudio/express
- **Hardware**
  - Purchase from http://www.microchipdirect.com or Development Tools store at discount
    - **PICDEM.net™ 2 development board (DM163024)**
    - **MPLAB ICD 2 debugger (DV164005)**
    - **9V power supply (AC162039)**

Thank You!
Questions?

References

- AN833 – The Microchip TCP/IP stack
- AN1044 – Data Encryption Routines for PIC24 and dsPIC® DSC Devices
- AN953 – Data Encryption Routines for the PIC18
- PICDEM.net™ 2 Users' Guide
- Microsoft Visual Studio Express Edition tools – http://msdn.microsoft.com/vstudio/express/
- Internet RFCs – http://www.faqs.org/rfcs/ or alternate sources

Appendix

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TCP Functions

- TCPInit
- TCPListen(…)
- TCPConnect(…)
- TCPIsConnected(…)
- TCPDisconnect(…)
- TCPIsPutReady(…)
- TCPPut(…)
  TCPPut[ROM]Array(…)
  TCPPut[ROM]String(…)
- TCPFlush(…)
- TCPIsGetReady(…)
- TCPGet(…)
  TCPGetArray(…)
- TCPProcess
- TCPTick

TCP Application Examples

- **World wide web (HTTP/HTTPS)**
- **Email (SMTP/POP3)**
- **File and print servers**
- **Remote control (Telnet/SSH)**
- **Turn based multiplayer games**
  - Board games
  - Card games

UDP Functions

- UDPInit
- UDPOpen
- UDPClose
- UDPIsPutReady(…)
- UDPPut(…)
  UDPPut[ROM]Array(…)
  UDPPut[ROM]String(…)
- UDPFlush
- UDPIsGetReady(…)
- UDPGet(…)
  UDPGetArray(…)
- UDPDiscard
- UDPProcess

UDP Application Examples

- **Real time multiplayer games**
  - First person shooters
  - Real time strategy
  - Action/adventure
- **Voice over IP (VoIP) telephones**
- **Industrial automation**
- **VPN tunnels**
- **Some streaming audio/media protocols**
- **DHCP, DNS, SNMP, TFTP, NBNS, SNTP**

Blocking LCD

- **Interfaces to 16x2 character LCD**
- **Available API Functions**
  - LCDText[33] byte array
    - User accessible memory to write to
  - LCDInit
  - LCDUpdate
    - Copies LCDText[] into the LCD
  - LCDErase
    - Clears all characters in the LCD

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