CADR - Working

- In CADR, each node evaluates an information/cost objective and routes data based on the local information/cost gradient and end-user requirements.
- The information utility measure is modeled using standard estimation theory.
- Since CADR diffuses queries by using a set of information criteria to select which sensors to get the data, simulation results confirmed that it is more energy efficient than Directed Diffusion where queries are diffused in an isotropic fashion, reaching nearest neighbors first.

CDAR Conclusion

Constrained Anisotropic Diffusion Routing (CADR)

- General form of Directed Diffusion
- Query Sensors
- Route data in the network
- Activates sensors close to the event and dynamically adjusts routes
- Routing based on a local information/cost gradient
- More energy efficient than Directed Diffusion

Two-Tier Data Dissemination Protocol (TTDD)

This section presents the basic design of TTDD, which works with the following network setting:

- A vast field is covered by a large number of homogeneous sensor nodes which communicate with each other through short-range radios. Long-range data delivery is accomplished by forwarding data across multiple hops.
- Each sensor is aware of its own location (for example, through receiving GPS signals. However, mobile sinks may or may not know their own locations.
- Once a stimulus appears, the sensors surrounding it collectively process the signal and one of them becomes the source to generate data reports.
- Sinks (users) query the network to collect sensing data. There can be multiple sinks moving around in the sensor field and the number of sinks may vary over time.

TTDD

Two-Tier Data Dissemination approach to address the multiple, mobile sink problem.

- Instead of propagating query messages from each sink to all the sensors to update data forwarding information, TTDD uses a grid structure so that only sensors located at grid points need to acquire the forwarding information.
- Upon detection of a stimulus, instead of passively waiting for data queries from sinks – the approach taken by most existing work – the data source proactively builds a grid structure throughout the sensor field and sets up the forwarding information at the sensors closest to grid points (henceforth called dissemination nodes).

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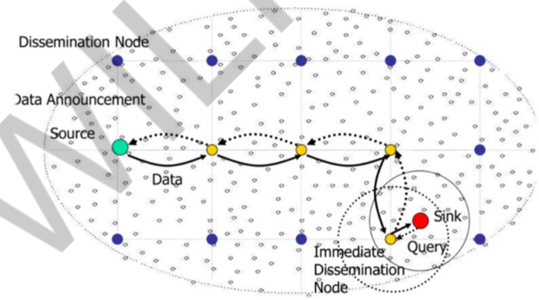
TTDD - Working

- With this grid structure in place, a query from a sink traverses two tiers to reach source.
- The lower tier is within the local grid square of the sink's current location (henceforth called cells), and the higher tier is made of the dissemination nodes on the grid.
- The sink floods its query within a cell. When the nearest dissemination node for the requested data receives the query, it forwards the query to its upstream dissemination node toward the source, which in turns further forwards the query, until it reaches either the source or a dissemination node that is already receiving data from the source (e.g., upon requests from other sinks).
- This query forwarding process provides the information of the path to the sink, to enable data from the source to traverse the same two tiers as the query but in the reverse order.

TTDD



TTDD - Conclusion

- TTDD, a Two-Tier Data Dissemination design, solves the problem by utilizing a grid structure.
- The fact that sensors are stationary and location-aware allows each data source to build a grid structure in an efficient way.
- TTDD lets data sources flood sensing data to reach all potential sink locations.
- Data flooding is forwarded only to a small set of sensors located on the grid points.
- Each mobile sink floods its data queries to express its interest, however different from previous work such flooding is limited to be within a single cell of the grid structure only.
- TTDD can effectively deliver data from multiple sources to multiple, mobile sinks with performance comparable with that of stationary sinks.

- *Reference - Luo, H., Ye, F., Cheng, J., Lu, S. and Zhang, L. (2005)* ***TTDD Two-Tier Data Dissemination in Large-Scale Wireless Sensor Networks****. Wireless Networks, 11, 161-175*

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Energy Efficient MAC Protocols

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MAC - Medium Access Control

"The primary goal of MAC protocols for WSNs is energy efficiency."

- Prolong Network life time
- High energy efficiency
- Code size
- Memory

MAC - Medium Access Control

Performance parameters - Secondary Role

Throughput and Bandwidth utilization

Latency: A delay via the network.

Jitter: A change in the amount of latency.

MAC protocols for WSN

Classification

- Contention based
- Schedule based

Comparison

- Contention based
  - Energy consuming
  - Has idle listening, over hearing and collisions
  - Low implementation complexity, scalable, flexible

Communication patterns in WSN

- Broadcast
- Local gossip
- Convergecast
- Multicast

Communication Pattern

Broadcast: A base station (or a sink node) sends data to all the sensor nodes in the WSN.

Local gossip: Neighboring nodes communicate with each other locally, following the detection of an event.

Convergecast: A group of sensors communicate what they perceived to a specific sensor.

Multicast: A sensor sends a message to a specific subset of sensors – cluster based protocols.

Causes of energy wastage

- Collisions
- Overhearing
- Protocol overheads
- Idle listening
- Overemitting

Causes of Energy Waste in WSNs

Collisions - Packet is corrupted due to a collision - a random back-off .

Over hearing - Receive packets that are not destined for it.

Idle listening - Listening to receive possible traffic that is not sent.

Protocol overhead - Sending and receiving control packets

Over emitting - When a node sends a message and the destination node is not ready to receive.

Performance Metrics for MAC Protocols Used in WSNs

- Throughput and delivery ratio.
- The energy consumption is directly related with the duty cycle of nodes or with the average sleep time.

WSN MAC Protocols - Timeline

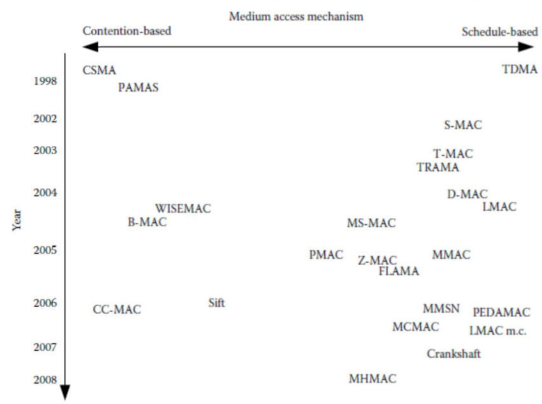


FIGURE 8.1 Classification of MAC protocols for WSNs.

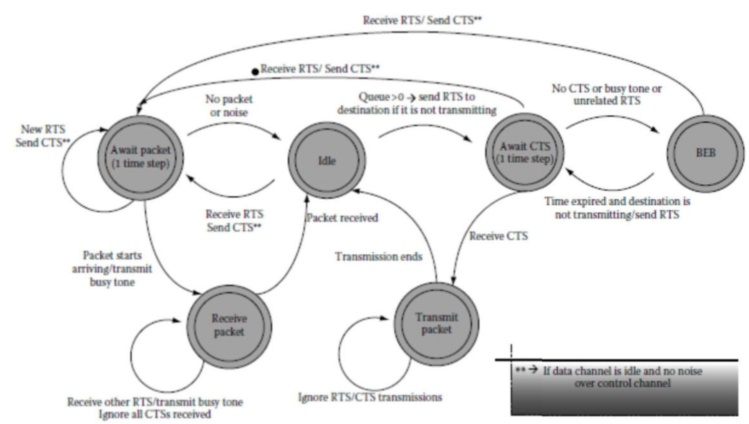
MAC protocol - PAMAS

Power-Aware Multi-Access Protocol with Signaling (PAMAS) – the idea of switching off the radio of nodes when they are likely to overhear transmissions,

RTS / CTS

RTS/CTS (Request To Send / Clear To Send) is the optional mechanism used by the 802.11 wireless networking protocol to reduce frame collisions introduced by the hidden node problem

RTS / CTS



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RTS / CTS

Two separate channels, one used for signaling and one for data transmission.

How long the node should be switched off –

1. If a packet transmission in the neighborhood begins while the node is still switched on.
2. If there is an on-going transmission when the node is back and switches on the radio.

Probe packets :

Packets that each device sends automatically, from time to time, searching all around to see if X-known network is nearby, so they can connect. All devices do this to all known networks as soon as we "turn on" the Wi-Fi.

MAC protocols for WSN

Schedule based

- Energy efficient and collision free
- Complex to implement
- Schedules are broadcast in advance
- Limits scalability especially in handling mobile nodes

MAC protocols categories

- A pure carrier-sense multiple access (CSMA) .
- A pure time division multiple access (TDMA) protocol.

Berkley MAC (BMAC)

- Carrier Sense MAC
- Low power operation
- Collision avoidance
- Reconfigurable by network protocols
- Tolerant to changing network condition

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BMAC Components

- Clear Channel assessment (CCA)
- Packet backoff
- Link layer acknowledgement
- LPL (Low Power Listening)

CSMA-CA

Listen	Listen for a pre determined amount of time for network activity
Send	If idle, send packet
Back off	If channel busy, back off for random time

Clear Channel Assessment (CCA)

- Detect signal, also isolate noise
- B-MAC uses software to determine ambient noise
- It searches for outliers which lie below the noise floor
- If the channel is clear then transmit
- If channel is busy then back off

B-MAC implementation

- Low power Listening (LPL)
  - When node awakens, it checks for channel activity using CCA
  - If activity detected, stay awake and receive packet
  - If no packet, then post timeout go back to sleep
- Preamble length
  - Should be as long as duty cycle

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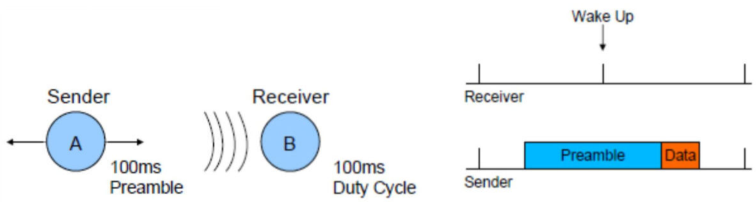
B-MAC



B-MAC implementation

Code
- Small code size

Protocol	ROM	RAM
B-MAC	3046	166
B-MAC w/ ACK	3340	168
B-MAC w/ LPL	4092	170
B-MAC w/ LPL & ACK	4386	172
B-MAC w/ LPL & ACK + RTS-CTS	4616	277

B-MAC implementation

Link Layer acknowledgement — Provided if configured on receipt of a unicast message

Parameter adjustment — Minimises nodes energy consumption and maximises life time

Traffic Adaptive Medium Access (TRAMA)

Uses transmission schedules to avoid collision
Uses adaptive power switching policy
Working
- TDMA
- Single channel for data and signalling
- Scheduled access slots are used for data
- Random slots for signalling

TRAMA

Random access slots

Contention based channel access

Transmitters reserve slots for transmission

Components

Neighbour Protocol (NP)

Schedule Exchange Protocol (SEP)

Adaptive Election Algorithm (AEA)

TRAMA

NP

- Used for exchanging one hop neighbour information
- Active during random access slot

SEP

- Used for exchanging schedules with neighbours
- Contains information on traffic coming from nodes
- Schedule is announced before transmission using SEP

TRAMA

AEA

- Coordinates between transmitters and receivers to achieve collision free transmission
- Uses traffic information-Source node and dest. Node

Mobility in WSN

- Weak mobility
  - Change in topology
  - Node failure
  - Node join
- Strong mobility
  - Physical mobility
  - Sink mobility

Mobility aware MAC

- Designed to support mobile sensors
- Use adaptive mobility handling mechanism
- Mobility of nodes determined through the signal strength
- Variation in strength signifies mobility
- In case of multiple mobile nodes, node with highest estimated speed is included

Mobility Aware MAC

- Active zone created around moving node
- Synchronisation period is low in Active zone
- High energy consumption
- Time to setup new connection shorter

Mobility Adaptive Collision free MAC

- Uses scheduled and random time slots
- Division between scheduled and random slots changed adaptively
- Changes done on basis of expected mobility
- NMAC assumes node is location aware
- Location information used to predict mobility pattern
- Mobility patter is used to reduce frame time

Mobility adaptive MAC

- Different slots are used for mobile and static nodes
  - Scheduled slots used for static nodes
  - Contention slots used for mobile nodes
- Nodes determine whether they are mobile or static using mobility estimation algorithm

Multichannel MAC

- Use hybrid approach- combine FDMA with TDMA and CSMA
- Enhance network capacity
- Challenges
  - NIC can work only on one channel at a time
  - Multi channels cause drain on energy
  - Channel deafness- Node A transmits to node B, however node B is transmitting to node C on a different channel
  - Co-existence of unicast ad broadcast messages

Multi frequency MAC (MMSN)

Two parts
- Frequency assignment
- Media access

Frequency assignment used when available bandwidth cannot accommodate all nodes

Frequency assignment

- Exclusive frequency assignment
  - Use node ID ,higher ID, higher frequency
- Even selection
- Eavesdropping
- Implicit consensus

Multichannel MAC

- Channels are dynamically selected
- Uses network clusterisation
- Cluster heads
  - collect request messages from members
  - Select radio channel
  - Communicate to members
- Introduces significant overheads due to signalling messages

Sensor MAC (S-MAC)

S-MAC aim is to reduce energy in - idle listening, collisions, overhearing, and protocol overhead.

Three major components:

- Periodic listen and sleep scheme
- Collision and overhearing avoidance mechanism
- Message passing

FRAME

An entire cycle of listen and sleep is called a frame.

- Listening interval = radio bandwidth and the contention window size
- Duty cycle = ratio of the listening interval to the frame length.

S-MAC the listening period is significantly longer than typical clock drift rates.

Listening interval is divided into two parts.

1. The first part is for receiving SYNC packets
2. Receiving DATA packets.

S-MAC

The latency increases due to the periodic sleep of the receiver, which makes the sender wait for the receiver to wake-up before it can send out data.

Timeout-MAC (T-MAC)

Reduces idle listening by transmitting all messages in bursts of variable length and sleeping between bursts.

To determine the end of the active period T-MAC uses a timeout mechanism.

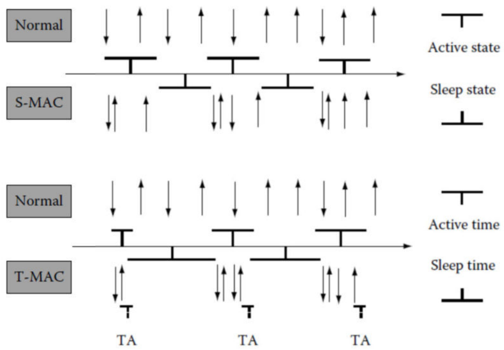
T-MAC provides two mechanisms, the future request-to-send (FRTS) and the full-buffer priority options.

FRTS mechanism provides for sending an FRTS packet when a CTS destined for another node has been overheard

The full-buffer priority solution gives priority to a node with full buffer.

Drawback of T-MAC is the early-sleeping problem.

Duty Cycle Comparison



Data-Gathering MAC

Multi hop - MAC protocols for multi-hop WSNs that utilize listen/sleep duty cycles suffer from the so-called data forwarding interruption problem.

The Data-Gathering MAC (DMAC) - is an energy-efficient low-latency protocol designed and optimized to solve the data forwarding interruption problem in convergecast WSNs.

DMAC can be viewed as an extension of the Slotted Aloha algorithm.

T-MAC, DMAC also adjusts the duty cycles adaptively according to the network workload.

When collisions are likely to occur, i.e., in event-triggered WSNs, DMAC performance degrades.

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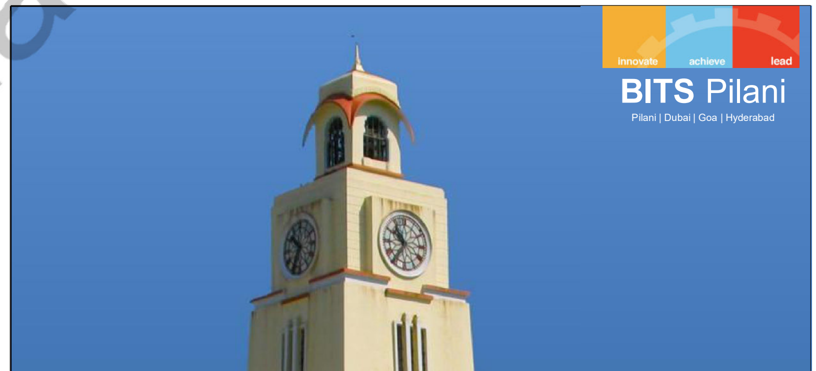

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Energy Efficient MAC Protocols (contd) and Case study

MAC – Numerical 1

A sensor node using the Berkeley MAC (B-MAC) protocol is configured with a preamble sampling interval of 500 ms. The transmitter needs to send a packet to a receiver and must ensure the receiver is awake to detect the packet. If the data transmission (excluding the preamble) takes 10 ms, and the preamble length equals the sampling interval, calculate:

1. The total transmission time from start of preamble to end of data.
2. The total energy consumption if the node transmits at 20 mW during preamble and 30 mW during data transmission.

MAC – Numerical 1

1. Total Transmission Time:

- Preamble length = Sampling interval = **500 ms**
- Data transmission time = **10 ms**

Total transmission time = Preamble time + Data time = 500 ms + 10 ms = 510 ms

2. Total Energy Consumption:

- Preamble energy = Power × Time = **20 mW × 500 ms = 20 × 0.5 = 10 mJ**
- Data energy = **30 mW × 10 ms = 30 × 0.01 = 0.3 mJ**

Total energy = 10 mJ + 0.3 mJ = 10.3 mJ

Total Energy Consumption

Assume a B-MAC node transmits a packet every 10 seconds. The preamble duration is equal to the receiver's sampling interval. Compare energy consumption per transmission for two sampling intervals: 200 ms and 500 ms. Assume preamble power = 20 mW.

Solution

- Case A: Preamble = 200 ms → Energy = 20×0.2=4 mJ
- Case B: Preamble = 500 ms → Energy = 20×0.5=10 mJ

- **200 ms sampling interval:** 4 mJ
- **500 ms sampling interval:** 10 mJ
- **Trade-off:** Lower sampling interval reduces energy per transmission but increases idle listening energy.

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Latency

Assume the receiver samples the channel every 400 ms. What is the **maximum and average latency** to detect a transmission in B-MAC?

Latency

Assume the receiver samples the channel every 400 ms. What is the **maximum and average latency** to detect a transmission in B-MAC?

Solution:

- **Maximum latency:** Equal to sampling interval = **400 ms**
- **Average latency:** Half of sampling interval = 400÷2=200 ms

Energy Savings from Sleep scheduling

A sensor node using S-MAC has a **duty cycle of 10%**, meaning it sleeps 90% of the time.

If the radio consumes **50 mW when active** and **2 mW when sleeping**, calculate the

Average energy consumption over a 1-second cycle.

Energy Savings from Sleep scheduling

A sensor node using S-MAC has a **duty cycle of 10%**, meaning it sleeps 90% of the time.

If the radio consumes **50 mW when active** and **2 mW when sleeping**, calculate the

Average energy consumption over a 1-second cycle.

Solution:

- Active time = 10% of 1s = 0.1s → Energy = 50 mW × 0.1s = 5 mJ
- Sleep time = 0.9s → Energy = 2 mW × 0.9s = 1.8 mJ
- Total energy per second = 5 + 1.8 = **6.8 mJ**
- Average energy = **6.8 mJ**

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Throughput Calculation

Assume a node using S-MAC transmits **100-byte** packets during each 0.5-second listen period. If transmission takes 40 ms, how many packets can be sent per listen period, and what is the effective throughput in a 2 second period?

Throughput Calculation

Assume a node using S-MAC transmits **100-byte** packets during each 0.5-second listen period. If transmission takes 40 ms, how many packets can be sent per listen period, and what is the effective throughput in a 2 second period?

Solution:

- Listen time = 0.5 s = 500 ms
- Max packets = 500 / 40 = **12 packets**
- Throughput = 12 × 100 bytes = 1200 bytes per 2-second cycle (0.5s active + 1.5s sleep)
- Throughput = (1200×8)÷2=4800 bits per second = **4.8 kbps**
- **Answer: 12 packets per listen period, 4.8 kbps effective throughput**

A comprehensive overview of the design, development, and deployment of a Wireless Sensor Network (WSN) for agriculture spread over vast lands.

The Need…

1. Over watering resulting in water wastage and damage to crop.
2. Watering when the soil temperatures are high.
3. Low water level in bore well resulting in dry run of pumps and wastage of power.
4. No timely information or messages to the farmer(s) on the over all status such as:
   a. Pump ON/OFF status,
   b. low Water level in bore well,
   c. availability of three phase electricity,
   d. soil moisture,
   e. high or low soil temperatures.
5. No proper data for agronomists to advice farmers.

System conception

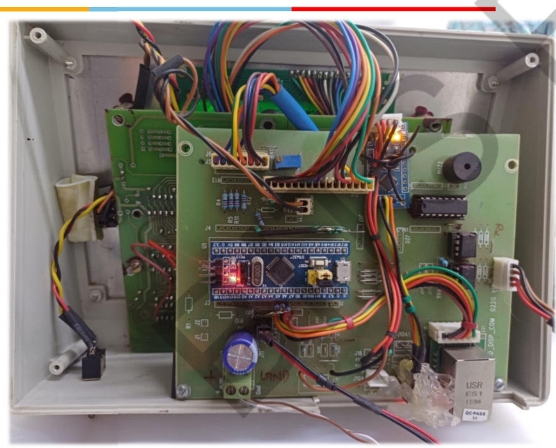
The project was conceived with the goal of leveraging low-power, distributed sensing technology to gather real-time data from remote locations in the field with provision to expand the nodes and/or ability to add more and/or different sensors as and when required.

The general layout of agricultural fields comprises of vast lands with a bore well (in some cases multiple), a pump and electrical supply lines drawn to the pump. The water from the pump is generally channelled to different parts of the field.

Major System components

1. Hardware comprising of a master (sink), several nodes (maximum 12 per installation) interfaced to different sensors.
2. Firmware for master (sink) and firmware for nodes (devices)
3. Software on a server to log data from many sites and provide data to agronomists and provide guidance to farmers and also to study effects of various parameters on the crops.

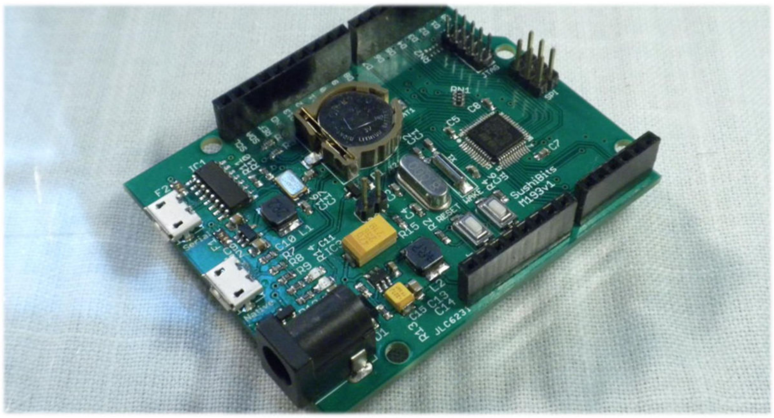
Agrimaster



Hardware of master or sink

- The master is based on the popular 32 bit ARM controller from ST Micro Electronics (ATM32F103).
- ARM controllers are known for their low power consumption, speed of operation, versatility, availability of software tools, ease of developing, modifying, upgrading the firmware, availability of the chips, lead times and the cost; hence the selection of these controllers.
- One of the important features required is the power consumption of the controller and the entire circuit in general.
- ARM controllers offer excellent power saving by way of different sleep modes.
- Master is provided an LCD for display of messages locally while the not in sleep mode.

ATM32F103 Module



Master contd ….

Power supply for master and nodes:

- Both the master and the nodes are powered by batteries of sufficient capacity to last for 48 hours and more.
- Batteries are charged by solar panels by an independent MPPT charger attached to the solar panel.
- Both master and the nodes are expected to work round the clock, but in intervals which is selectable.

Master contd ….

- The master (sink) itself acts as one node in addition to controlling and collecting sensor data from various nodes.
- The master has two communication channels.
  - One GSM/GPRS (mobile data SIM based) and the other LoRa (sub1 GHz) channel.
  - LoRa is used for local communication between the nodes and master.
  - GSM/GPRS is used for communicating with the remote server.
  - Master and nodes have an RS232 serial port for configuring. Debugging, testing can be done by way of commands.

GSM Module

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Master (GSM and SIM)

- Some mobile service providers are offering NB-IOT (Narrow Band – IOT) SIM cards. It is preferred to use these wherever possible.
  - These have 11 and 13 digit mobile numbers.
- NB-IOT, is a specialized SIM designed for connecting low-power, low-data-rate devices to the internet via existing cellular networks.
  - This technology is optimized for long battery life, extended coverage (including indoors), and cost-effectiveness, making it ideal for various Internet of Things (IoT) applications.

Master contd ….

- Master (SINK), periodically queries each of the nodes for data through the LoRa network.
- Each node is given a node address and during this query time all nodes must be out of sleep and should have collected the data from all the sensors connected to them.
- After receiving the data from the node the master sends a "SLEEP MINUTES" command to the respective node.
- Nodes also run a Real Time Clock and the local alarm is set to the number of minutes sent by the master and switch to sleep (power saving) mode.

Master water level sensor

- Master has one special and extra sensor(optional) compared to the nodes - water level sensor.
- Where bore well is available, this sensor can be attached to the master and master can be configured through serial port commands the sensor connected.
- The configuration data is stored in non-volatile memory (FLASH). The firmware can check this configuration take appropriate action.
- The water level sensor uses a pressure sensor to detect the water column height above the sensor.
- The sensor can easily detect 15~20 meters of water above the sensor.

Firmware snippets

Some firmware code snippets are shown below for understanding sequence of operations in the master.

The code is written 'C' programming language.

```
if (rc == 0) // time to acquire data from devices and send to server
 {
    power_on_GSM_nd_init();  // GSM modem
    enable_dns();     // this is to connect to named server
    fill_buffer_with_data ();
    data_2_server();  // open connection and send data to server
   GSM_POWER_OFF; // after sending data switch off power to
                                  // GSM and water level sensor
```


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Firmware snippets . . .

```
if (pump_status == 0)  // check pump status
  rc = 30;  // When pump is not ON and under normal conditions,
            // master sleeps for longer duration, so higher count to get
            // readings
  else
    rc = 6;      // master wakes up at short intervals when pump is ON
                 // so count has to be less

put_devices_2_sleep(NDB_DEV_SLAVE_SLEEP_TIME);
// Any devices which are awake, will go into sleep (300 seconds)
Mes2Usart1("Master Going in to deep sleep\r\n");
```


Firmware snippets . . .

Before sending data to server master checks the signal strength of GSM (mobile data)
get_gsm_signal_strength(void);

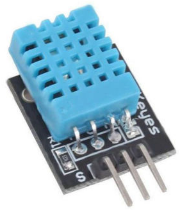
LoRa modules also support sleep mode for power saving. After local RF communication is done the LoRa modules are put in sleep mode to conserve energy by turning off radio.

Node description

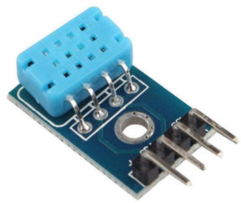
- The nodes are placed at different places in the field and are powered by batteries which are charged by solar panels. Thus, ensuring round the clock power to the nodes whenever needed.
- Nodes typically have temperature, humidity, soil moisture, soil temperature sensors attached to them.
- Nodes are equipped with LoRa transmitters and receivers. A typical line of sight LoRa communication can extend to more than a few kilo meters.
- It can achieve a range of up to 5-10 kilometres in urban areas and up to 20 kilometres or more in rural areas.
- Factors like obstacles, antenna height, and power output also play a role in the actual range achieved.

Node contd . . .

- For temperature measurement, the DS18B20 is used in both the node and master for soil temperature.
- For humidity and ambient temperatures, the DHT11and DHT12 sensors were used.



DHT 11



DHT 12

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Node contd . . .

Soil moisture sensor uses two probes of a PCB to detect the resistance between them and the PCB was designed and made for this project.

Each node is assigned a unique node ID. Master can either send a broadcast command/message or address a specific node by its unique ID. All the broadcast commands have no response from the nodes.

Node firmware description

- Communication between the master and the nodes is in ASCII, through the LoRa channel.
- Messages or commands start with node ID or 00 for broadcast.
- Nodes on receipt of a message, will first check if the message or command is intended for self.

The code snippet is

```
if (cmd != brdid)                    // not my ID
{
    Mes2Usart1("Not my ID\r\n");
    return;
}
```


Node firmware description contd . . .

- Several different commands are implemented in the nodes.
- One such command is the health query from master.
- The node responds to this query with a code.

Here is a code snippet.

```
switch (cmd) {
case 1:              // health query
    strcpy(g8_genbuf, "10\r\n");  // I am OK reply
    rply2mstr(g8_genbuf);
    break;
```

Messages from nodes also start with node address, so the master will know the origination (which node)

Conclusion

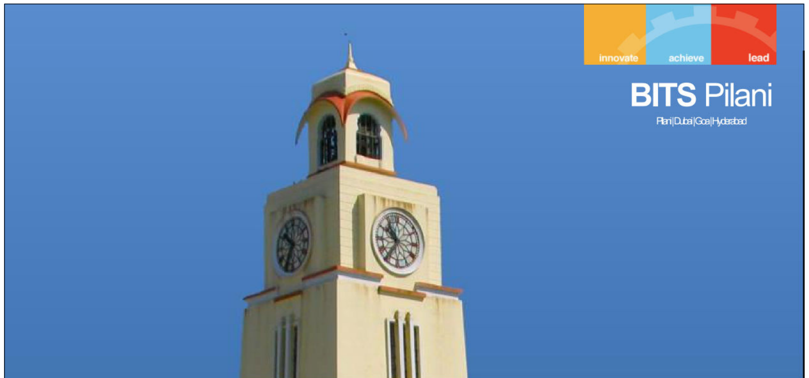
This is a live project and has been initially implemented in 5 sites across the country to test the functioning of the system and whether it is meeting the intended objectives.

As of date there are more than 35 sites in which this WSN has been implemented.

Improvements in communication, data collection are underway.

In some remote areas mobile data signals are either very weak or don't exist at all.

Using a second channel LoRa with repeaters where necessary and another base station where mobile signals are available, is under active consideration.



Questions?

IMP Note to Self

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Network Embedded Applications
(CSIW ZG656)

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Lecture No- 9

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Start Recording

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IMP Note to Students

- It is important to know that just login to the session does not guarantee the attendance.
- Once you join the session, continue till the end to consider you as present in the class.
- IMPORTANTLY, you need to make the class more interactive by responding to Professors queries in the session.
- **Whenever Professor calls your number / name ,you need to respond, otherwise it will be considered as ABSENT**

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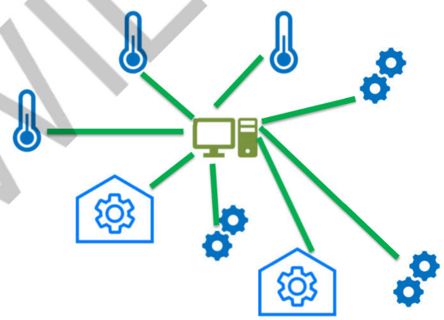
Field Bus ?

- Family of industrial computer network protocols used for real-time distributed control
- Standardized as IEC 61158
- Fieldbus – not a single protocol – many protocols

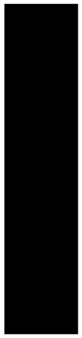
Industrial Networks - Historical



Industrial Networks

- Networks – integral part of manufacturing replacing point-to-point communication at all levels

Field Bus



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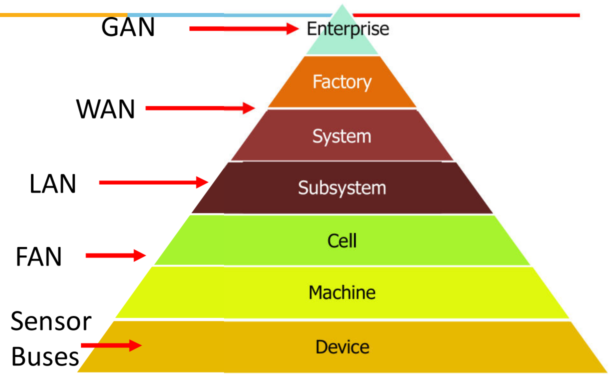
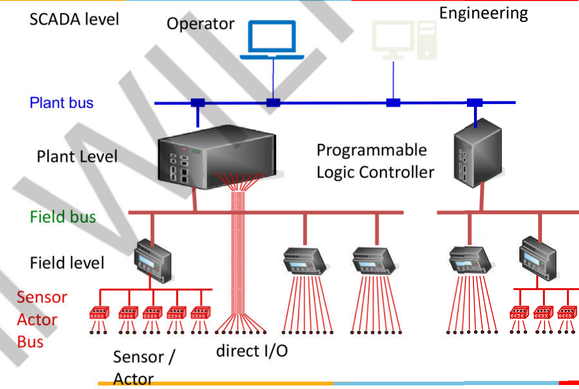
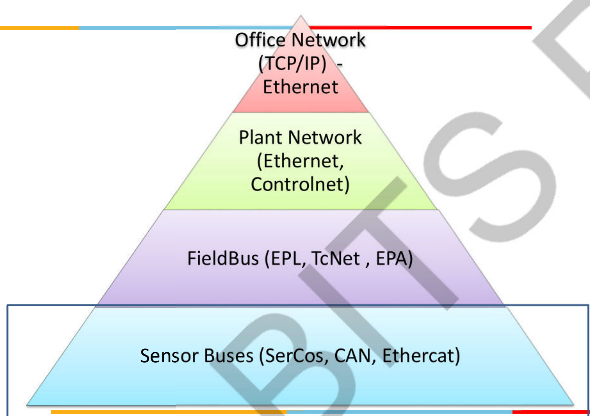
Computer Integrated Manufacturing



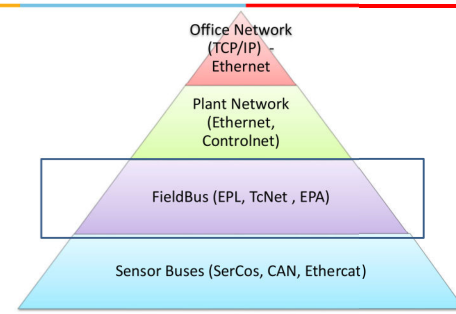
Plant Hierarchy



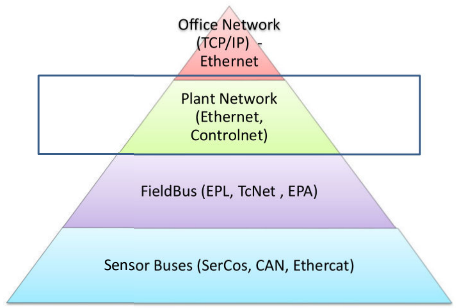
Industrial Communication Networks



Industrial Communication Networks



Industrial Communication Networks



Field Bus Classes

- The field bus depends on:
  - its function in the hierarchy
  - the distance it should cover
  - the data it should gather

Advantages – Lower Level

- High Reliability
- High Visibility
- High Diagnosability
- Enables
  - Distributed Control
  - Diagnostic
  - Safety
  - Device Interoperability

Advantages – Higher Level V1-end

- Enable factory wide automated scheduling
- Improves Data storage
- E-manufacturing
- Enables Data Visibility
- Increased capability of trouble shooting

Industrial Network History

History - v2-begins

- Based on ISO/OSI Model
- Manufacturing Automation Protocol (MAP) – 1982 – by GM

MAP

FTP, Manufacturing Messaging Format Standard (MMFS), MAP Directory Services & Network Management
Presentation - NULL
ISO Session IS 8327
ISO Transport IS 8073
Connectionless, Sub Network Dependent Convergence
IEEE 802.2 & IEEE 802.4 Token Passing Bus MAC
ISO Token Passing Bus (IEEE 802.4) 10 Mbps Broadband

History …

- Mini MAP
- Covers only Layer 1, 2 & 7
- Not very successful
- MMS - cooperation of various automation components by means of abstract objects & services

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History … v2-ends 5.37

- I2C (Inter Integrated Service)
- CAN (Controller Area Network)
  - Industrial
  - Automotive

Industrial Network Characteristics & Issues

Field Bus – Characteristics V3

- Focused solutions
- Smart Devices
- Limited Resources
- Comprehensive Concepts
- Distributed
- Flexibility & Modularity
- Maintainability

Primary Application?

- Factory wide solution for co-ordination of machine & process control

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Types of Networks

- Control
- Diagnostic
- Safety

Types of Networks- Control

- Sensory & Actuation info for closed-loop control
- control may be
  - time-critical - CNC / servo drive
  - event-based- PLC
- Guarantee a response time determinism

Types of Networks- Diagnostic

- Communication of sensory inform - to deduce health tool/ product/ system
- May "close-the-loop" - implement control capabilities - equipment shut-down/ continuous process improvement
- Performance - driven by the data collection
- Actuation is usually event-based
- Ability to communicate large amounts of data
- Determinism less important
- Data compression & security - communication between user & vendor to support equipment e-diagnostics

Types of Networks- Safety

- Safety is the newest of the three network sub-domains
- Requirements are often driven by standard
- Emphasis
  - Determinism guaranteed response time
  - Network reliability
  - Capability for self-diagnosis

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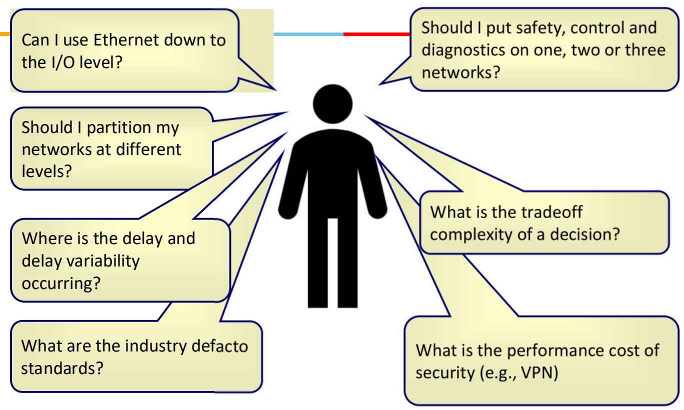
Issues - V3-end 9.5



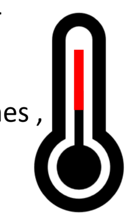
Industrial Network
Field Bus Characteristics

Field Bus – Characteristics V4-begins 4.5

- Link sensors, actuators, control units
- Traffic varies with Application Domain
  - Manufacturing
  - Process
  - Building
- Timing & Consistency
- Communication protocol & the services provided therein heavily influence the possible traffic types

Timing

- State sampled continuously at discrete intervals (temp & pressure)
- Data are transmitted only in case of state change (switches , anything that can be defined using a state machine)



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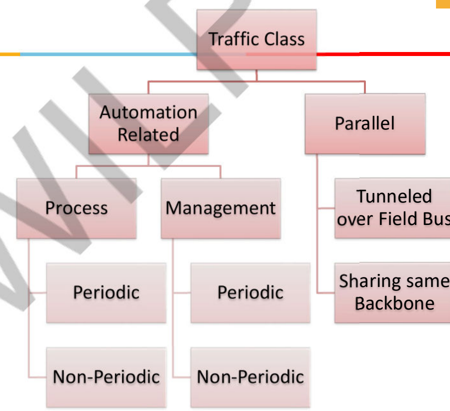
Consistency V4-ends 4.6

- Process data which are continuously updated
- Configuration (Parameterization) data – transferred on-demand

V5



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Process Data

- Cyclic / Identified traffic
- *Communication requirements* must be known once the application is specified
- Periodic or Aperiodic

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Process Data

- Periodic traffic
  - State of a process
  - Handled by TDMA or Variant
  - Each variable assigned a dedicated share of network bandwidth - apriori known sampling time
  - Frequency/ data update rate adaptive - current state of process
    - Alarm conditions - require more frequent sampling

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Process Data

- Aperiodic traffic
  - Generated on demand in an event-based manner
  - Transmitted - the availability of free bandwidth
  - Data transfer scheme is time-slot-based -spare slots / idle time explicitly reserved for this purpose

Process Data

- From an application point of view, process data typically are real-time data
- Tx & Rx occurs within a limited time window - meaningful for process control
- Aperiodic data -additional restriction of reliability

Management Data

- Parameterization or Configuration
- Data needed to set up and adjust operation of automation system
  - Settings of distributed application processes
  - Communication and network parameter
  - All network management data

Management Data

- Typically aperiodic - occur infrequently depending on state of complete system
- Often transmitted in some dedicated parameter channels - use a small amount of bandwidth left over by process data.

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Management Data

- May be required periodically or quasi-periodically
  - Exchange authentication info after a given number of messages
  - Change communication parameters on a routine basis
- Communication periodic management messages - do not differ from aperiodic ones
- They are simply invoked on a periodic basis

Management Data

- Mostly not real-time data
- More important -guaranteed & correct delivery

Parallel Data

- Does not belong to applications processes for actual control
- Generated by independent parallel processes - shares the communication medium
- Closed fieldbus systems - this type of traffic did not exist

Parallel Data

- Interconnect M2M network to the Internet – IoT -becomes relevant
  - External traffic routed/ tunnelled through the fieldbus
  - Fieldbus traffic routed through a shared backbone network

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Parallel Data

- Done by appropriate QoS- guarantee reasonable bandwidth & latency to fieldbus traffic in case a shared backbone is used.
- In reverse case - the fieldbus network management ensures - parallel traffic cannot consume arbitrary amount of communication resources / block processes

Industrial Network
Field Bus Network Model

Field Bus –Network Protocol Stack v6 begin

Appln layer
Link Layer
Physical

- Many field busses are single-segment networks
- Limited size
- Extensions are realized via repeaters/ bridges

Field Bus – Network Protocol Stack

- Building Automation domain – All Layers
- LONworks all seven layers
- BACnet – Network Layer
- EIB, Konnex – Network & Transport
- CAN/ Interbus – Have only Layer 1 & 2

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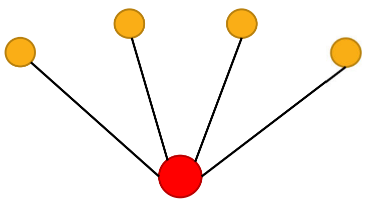
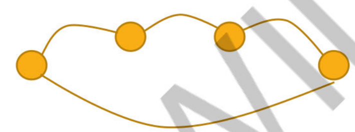
Network Topology - Star



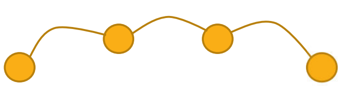
- Connecting Sensor/actuators to PLC
- Cabling Overhead

Network Topology - Ring



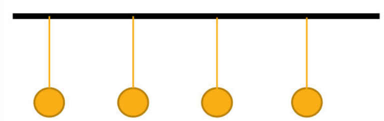
- In its entirety the ring can be viewed as one large shift register
- There is no need to address the nodes explicitly
- Very fast method to exchange data
- Very Deterministic – Low Jitter
- SERCOS, Interbus

Network Topology – Daisy Chain



- Profinet

Network Topology – Bus



- Most Commonly Used
- Extended using Repeaters, Bridges
- Crucial aspect -proper electrical termination of bus line to avoid signal reflections disturbing data transfer
- Leads to communication failures
- CAN

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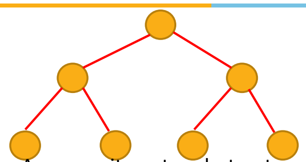
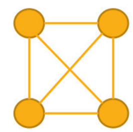
Network Topology – Tree



- A composite network structure
- Characterized by substations being dependent on a root node
- Each substation can in turn be a root node for lower-level segment
- In many cases, the actual connections between the stations are regular point-to-point connections or lines
- Build hierarchical, relatively complex networks
- Root nodes usually have routing capabilities
- LONworks BACnet, EIB – Building Automation

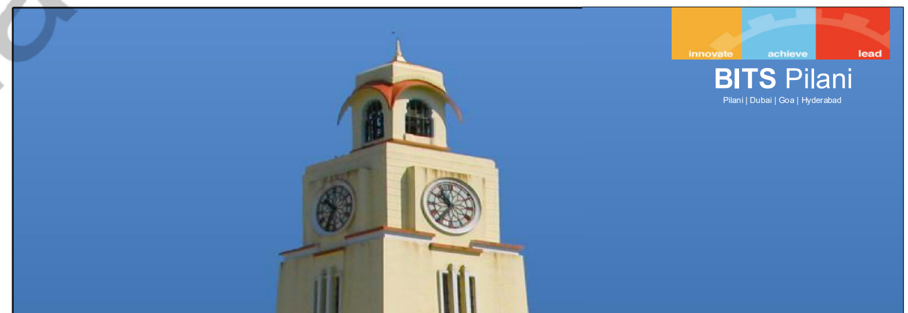
Network Topology – MESH



- Play only a subordinate role
- Require appropriate routing strategies to keep messages from circling in the network and causing congestion
- LONworks , P-NET

Role of Topology v6-end 11.12

- Influences - way access to the medium
- Topologies were often selected according to the desired MAC method or vice versa.



Industrial Network
Field Bus MAC

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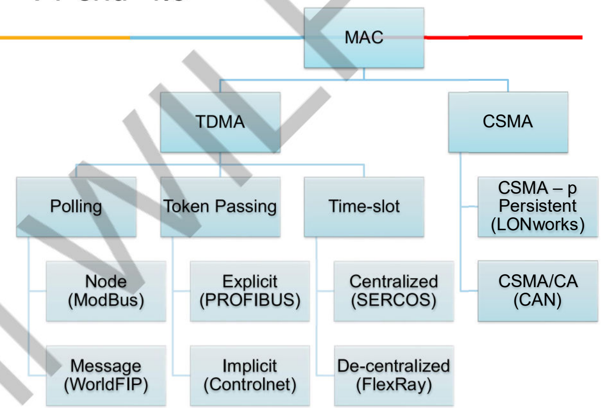
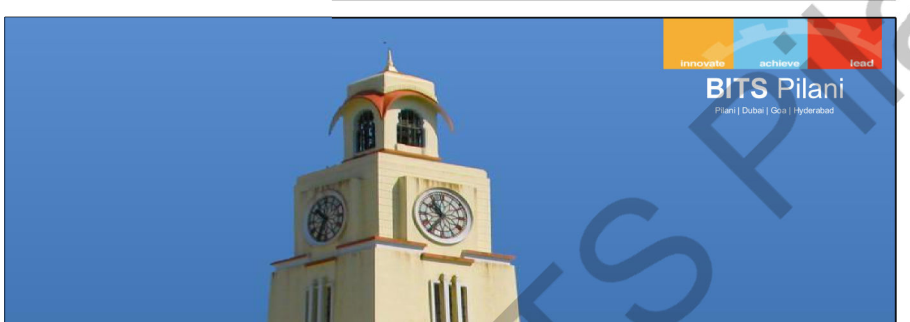
Field Bus –MAC V3.2 V1-begin

- Single-master / Master–slave
  - Fieldbus systems - lowest levels of the automation pyramid
  - Limited size, simple, single-segment structure
  - Request–response
  - Synchronized time slots
- Multi-master approach
  - Networks more complex / large scale
  - Usually at the cell-level

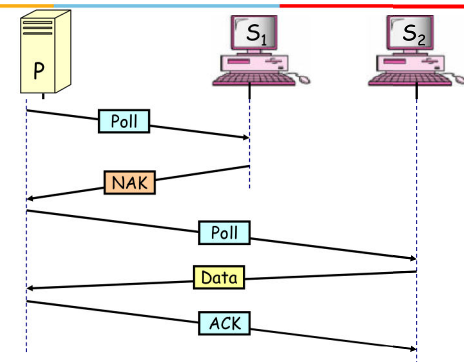
V3.1 –V1-end 4.6





Industrial Network
Field Bus MAC - TDMA

Polling R3.2-V2



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