CIS 721 - Real-Time Systems

Lecture 17: CAN Kingdom

Mitch Neilsen
neilsen@ksu.edu

Outline

Real-Time Communication

- **Controller Area Network Analysis**
- **Higher Layer CAN Protocols**
- **Time-Triggered Protocols (TTP/C, TTP/A,TTCAN)**

- Safety Critical Systems

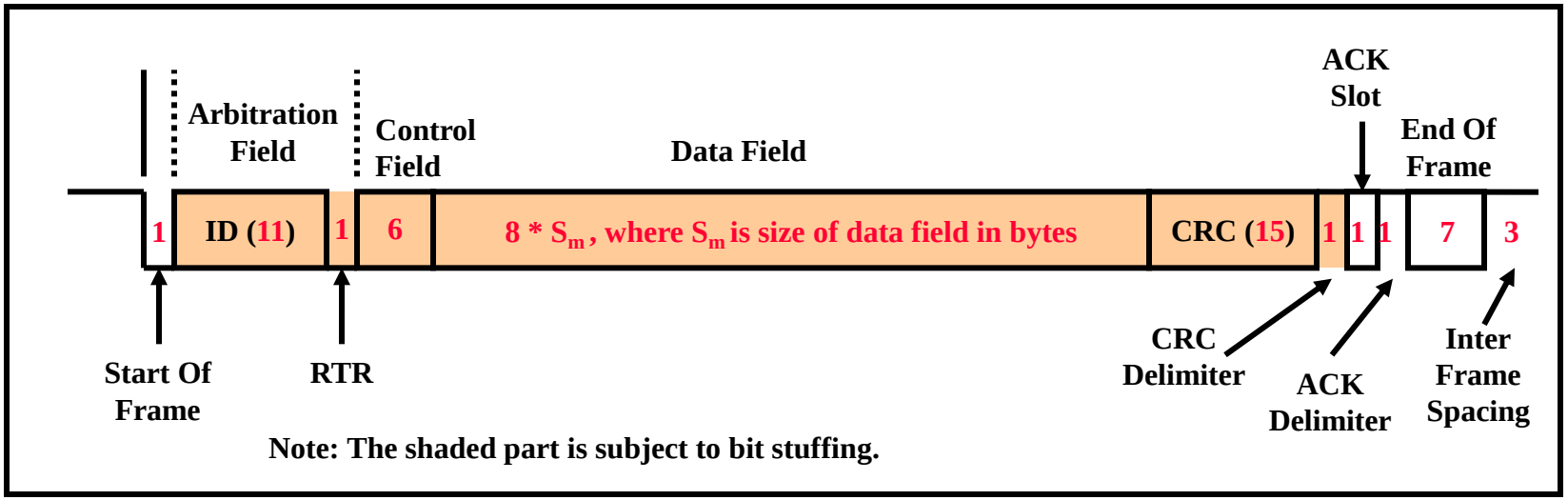
CAN Analysis - Assumptions

- Only **data frames** are transmitted on the bus, and no errors occur.
- All messages are transmitted periodically; however, messages may experience queuing delay, called **jitter**.

Data Frame Size

Data Frames are used to transmit messages to one or more receivers (multicast).

The CAN 2.0A Data Frame Format is shown below.

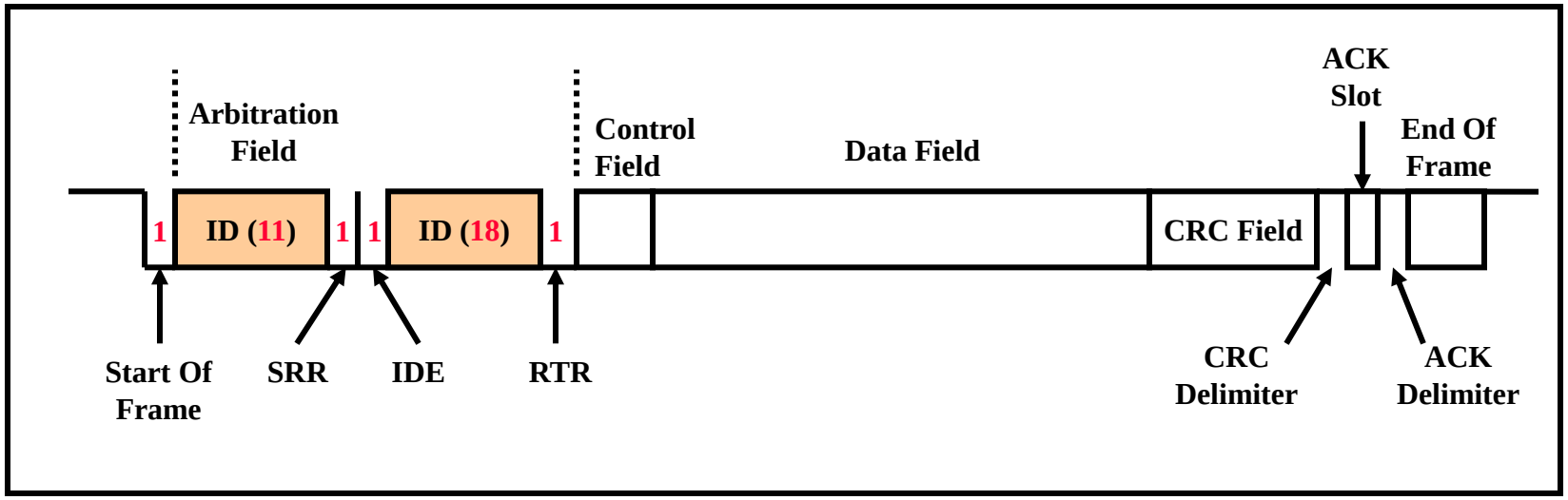


Worst-Case Tx Time (CAN 2.0A)

- Let C_m denote the worst-case transmission time for a data frame.
- For a data frame carrying 8 bytes of data:
  - $S_m = 8$
  - $C_m = 130 * \tau_{bit}$, where τ_{bit} is the bit transfer rate; e.g., for a 1Mbps CAN bus, τ_{bit} is 1 microsecond.

CAN 2.0B Format

- The CAN 2.0B Format uses a 29-bit identifier divided into an 11-bit base identifier and a 18-bit extended identifier.
- All other fields are the same as 2.0A.



Worst-Case Tx Time (CAN 2.0B)

- Let C_m denote the worst-case transmission time for a data frame.
- For a data frame carrying 8 bytes of data:
  - $S_m = 8$
  - $C_m = 154 * \tau_{bit}$, where τ_{bit} is the bit transfer rate; e.g., for a 250 kbps CAN bus, τ_{bit} is 4 microsecond.

CAN Analysis

- K. Tindell, A. Burns, and A. Wellings, “Calculating Controller Area Network (CAN) Message Response Times”, 1994.
- Use Classical Scheduling Theory to analyze controller area networks.
  - Response Time Analysis

Worst-Case Response Time

- The **worst-case response time** (R_i) for message i is given by $R_i = J_i + w_i + C_i$ where:
  - J_i is the **maximum jitter** of message i,
  - w_i is the **maximum queuing delay** of message i (due to both higher priority messages and a single lower priority message already on the bus); e.g., **interference + blocking time**, and
  - C_i is the **transmission time** of message i.

Response Time Analysis

- The **queuing delay** (w_i) for message i is given by the implicit equation:

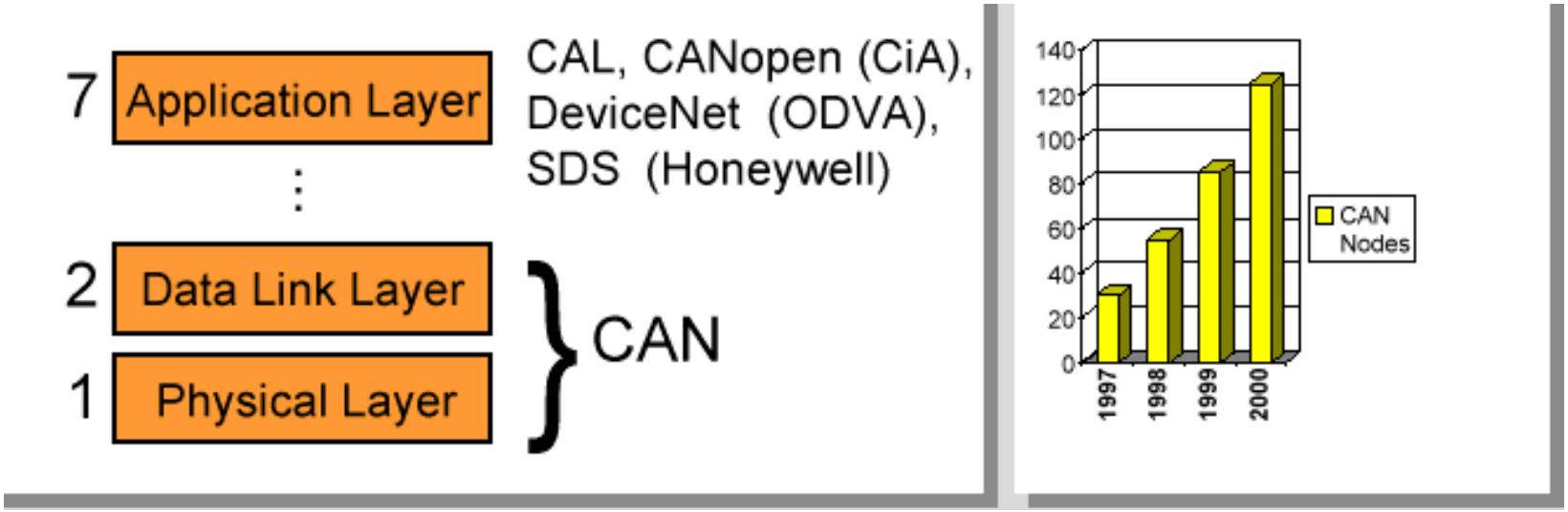
$$w_i = B_i + \sum_{j \in hp(i)} \left\lceil \frac{w_i + J_j + \tau_{\text{bit}}}{T_j} \right\rceil C_j$$

where B_i denotes **worst-case blocking time**:

$$B_i = \max_{j \in lp(i)} (C_j)$$

ISO Reference Model

- CAN protocols fall within the Data Link Layer and the Physical Layer.
- CAN is most widely used in the automotive and industrial automation markets.



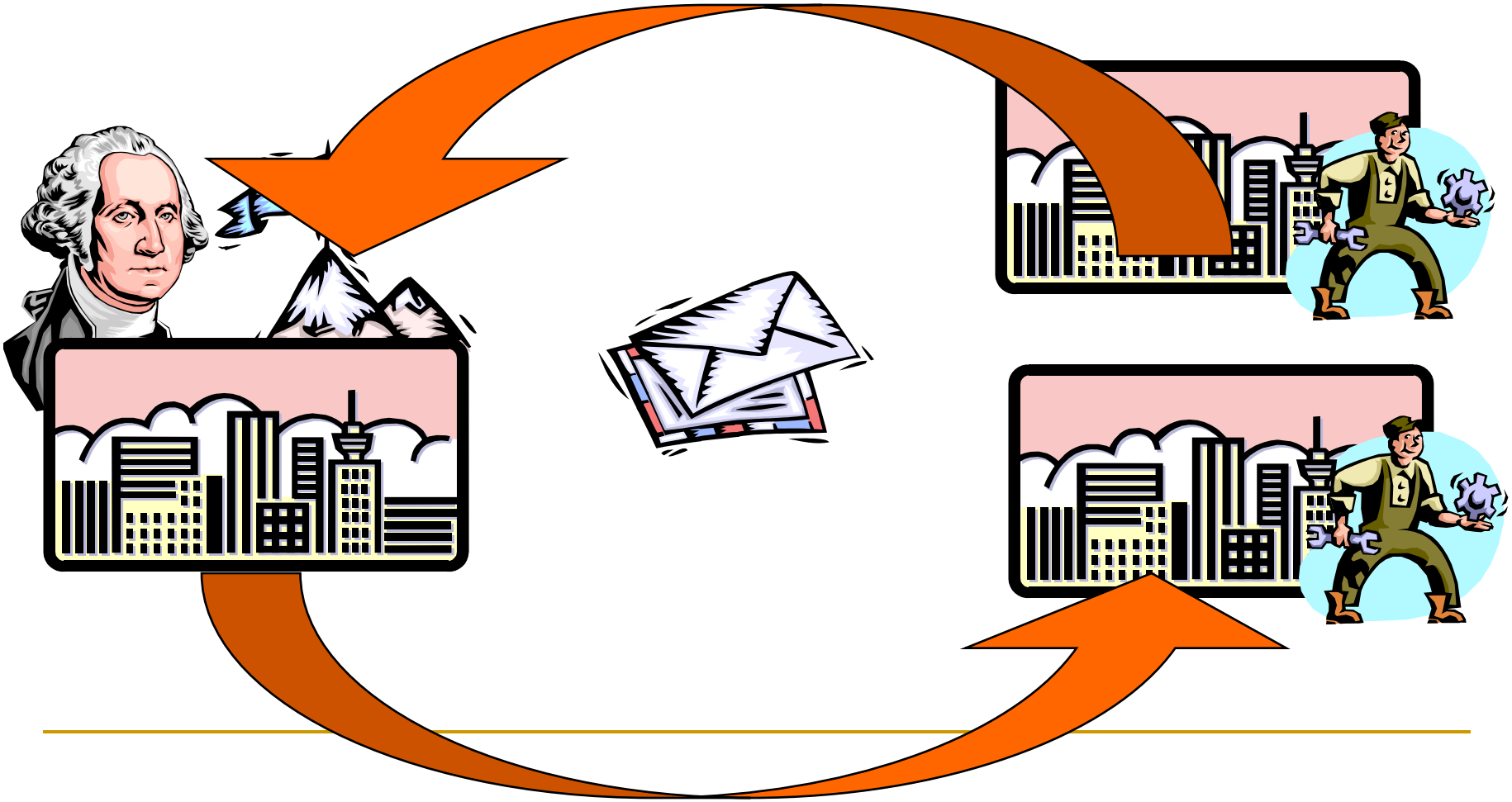
Higher Layer CAN Protocols

- **CAN Kingdom (Kvaser)**
- SAE J1939
- ODVA DeviceNet
- Honeywell Smart Distributed System (SDS)

CAN Kingdom

- CAN Kingdom is a higher-level meta protocol based on CAN.
- CAN Kingdom Vocabulary:
  - The system is a kingdom.
  - Each node is a city.
  - The CAN Network is the postal service.
  - Every system has a system designer called the king.
  - Every city has a mayor who runs the city.

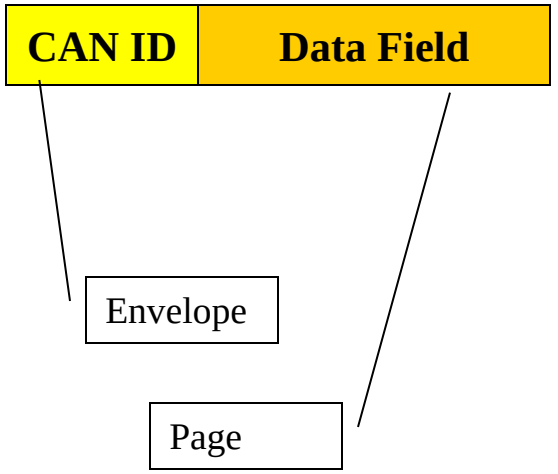
Of Kings and Mayors



How to deliver a letter?

- A letter is a sheet (page) of paper with an addressed envelope.
- The Postal Service delivers the mail (bulk junk mail or by address).
- In CAN Kingdom the CAN message is called a letter, the envelope is the CAN ID, and the data field is called a page.

Letter

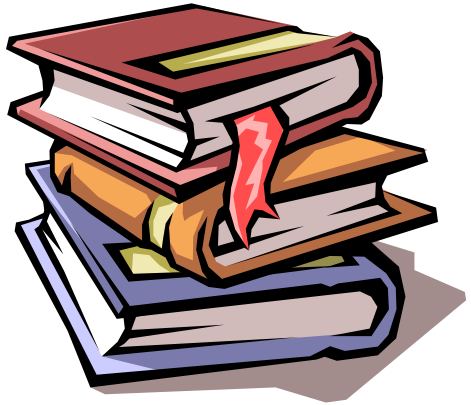


Post Office

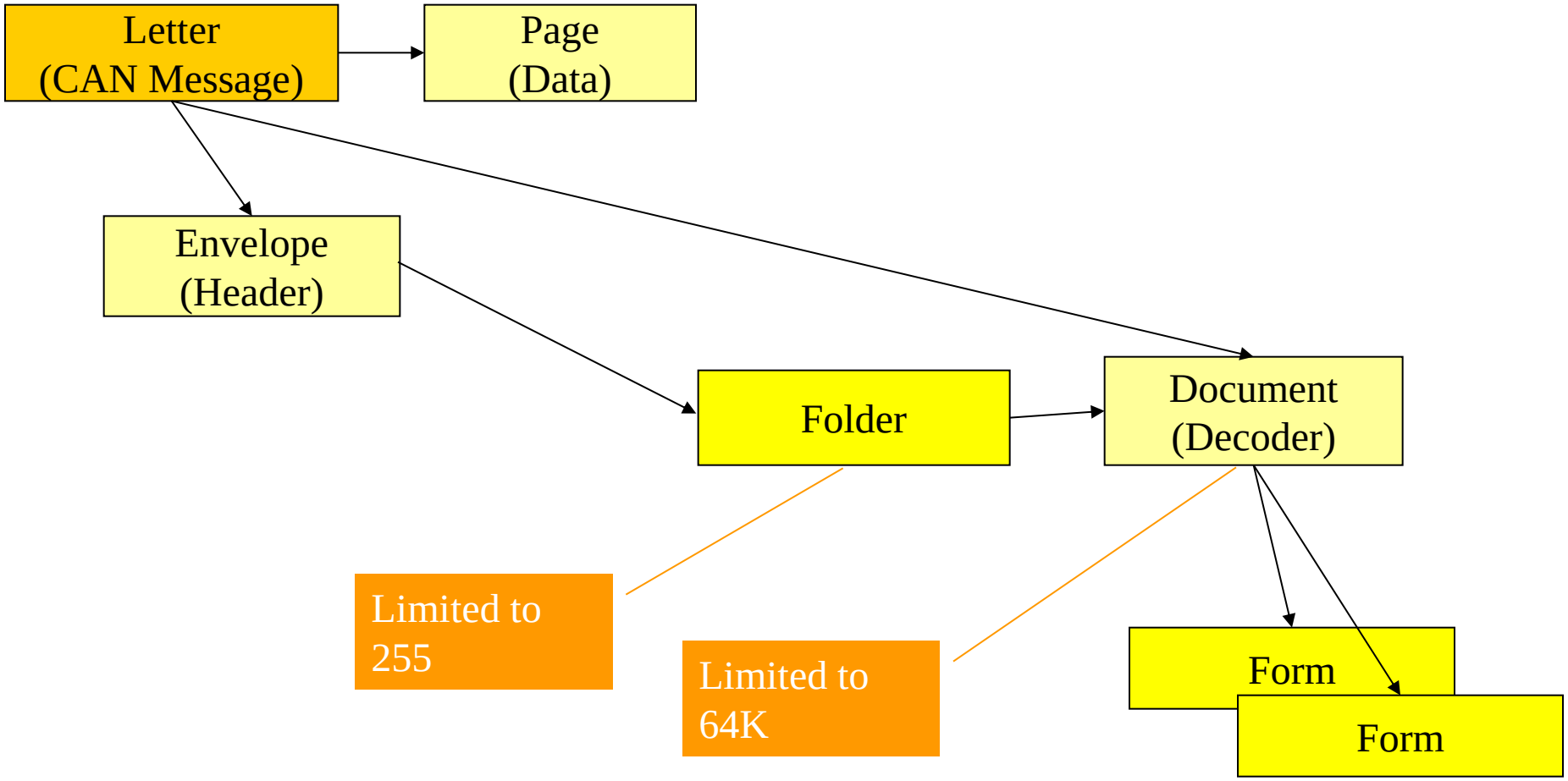
- Each node has a CAN Controller which is called a post office.
- Most CAN controllers have several rx/tx buffers which can be thought of as post office boxes (message objects). In CAN Kingdom, these buffers are associated with folders at run-time.

How do you read a letter?

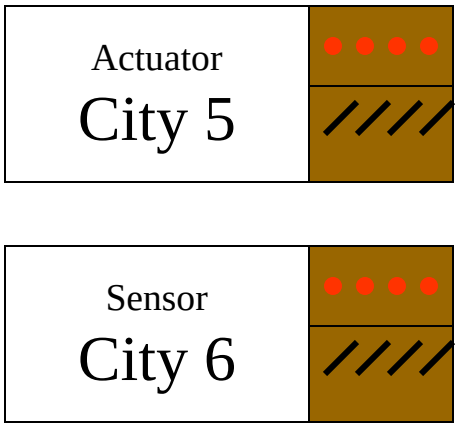
- Use rules for the language
  - grammar, spelling, alphabet
- CAN Kingdom calls these rules a document.
- CAN Kingdom allows a novel to be sent as a series of letters.
  - A document decodes the novel.
  - A form decodes each page of the novel.



Summary


Letter
(CAN Message)
Page
(Data)
Envelope
(Header)
Folder
Document
(Decoder)
Limited to
255
Limited to
64K
Form
Form

Simple Example



Consider cities with simulated sensors (slide bars) and simulated actuators (gauges).

We want some cities to transmit sensor data and other cities to receive actuator data.

The King is the Boss

The king tells the cities what to do:

- City 5, assign your actuator (gauge) document to folder 2.
- City 5 assign envelope 516 to folder 2.
- City 6 assign sensor (slider position) document to folder 4.
- City 6 assign envelope 516 to folder 4.
- City 6 send the position letter when the slider position changes.

How does the King do it?

- The King sends (what else) King's letters
  - The King's letter is part of a novel (which can be read out of order) or what is called a paginated document
  - That is, each letter has a page number that determines its meaning
- Even though these are letters, they are commonly called King's Pages or simply KP.
- There are only three required King's Pages:
  - KP0 controls starting/stopping of cities and bus access.
  - KP1 queries the mayor of a city for city information.
  - KP2 assigns envelopes to folders and enables/disables folders.

King's Page 0 (KP0)

- Terminates the setup phase.
- Orders a Mayor to set his City into a specific working mode:
  - Action Modes: Keep Current, Run, Freeze, or Reset,
  - Communication Modes: Keep Current, Silent, Listen Only, or Communicate.

King's Page 1 (KP1)

- Initiating Page.
- Provides the Base Number and asks for a Mayor's response.
- The Mayor of City n assigns (Base Number + n) to the envelope used to transmit the Mayor's response (e.g., unique ID).

Mayor's Letters?

- Each Mayor has its own letters.
  - These letters are used to identify the city.
- Like the King's Letters, each letter is commonly called a Mayor's Page or MP.
- Each city has two Mayor's Pages:
  - MP0 - EAN-13 Code
  - MP1 - Serial Number
- These two pages contain a unique 10 byte identifier.
- The default envelope is constructed from a base address and city number.

King's Page 2 (KP2) and 16 (KP16)

- **KP16**: Assign a document to a folder and enable or disable a folder. Specify folder properties including Data Length Code (DLC).
- **KP2**: Assign an envelope to a folder or change an existing assignment.

King's and Mayor's Pages

king's pages

Page 0 Start/Stop, Modes

Page 1 Base Number, Response Request

Page 2 Assign Envelopes

Page 3 Assign Groups

Page 4 Remove Groups

Page 5 Action Page - Reaction Page.

Page 8 Bit timing registers setting.

Page 9 New City physical address.

Page 10 Time Elapse.

Page 11 Circular Time Base Setup Page.

Page 12 Repetition Rate and Open Window Setup Page.

Page 16 Assign Documents to Folders.

Page 17 Create Documents, Forms or Lines from Lists.

Page 18 Create Compressed Letters.

Page 20 Create Filters for a Postmaster.

Block Transfer.

Time Herald.

mayor's pages

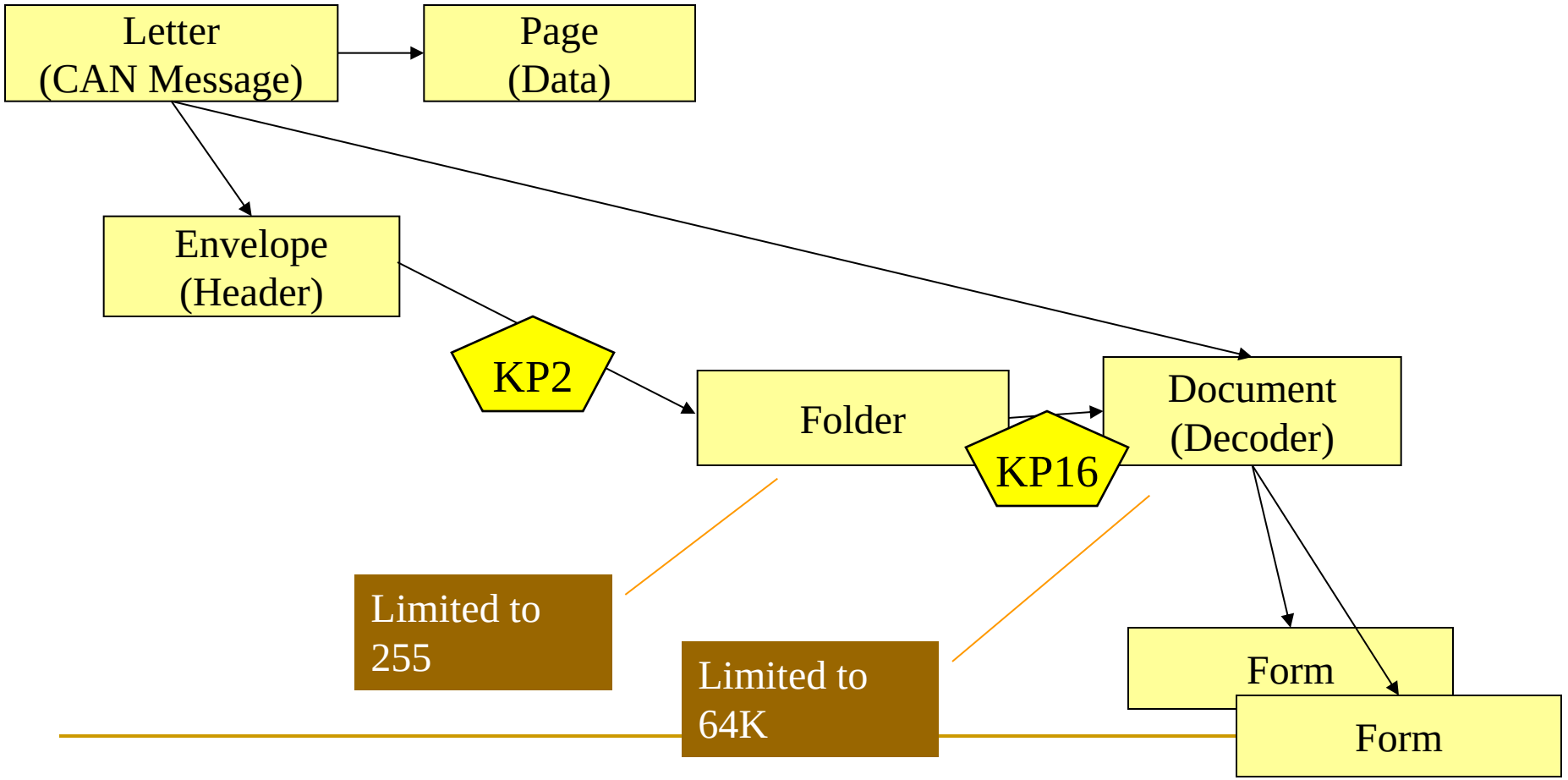
Page 1 EAN/UPC Code

Page 2 Serial Number

- Red = mandatory
- Black = optional

KVASER

KP2 and KP16


Letter
(CAN Message)
Page
(Data)
Envelope
(Header)
KP2
Folder
KP16
Document
(Decoder)
Limited to
255
Limited to
64K
Form
Form

King's Page 3 (KP3) and 4 (KP4)

- **KP3**: Assign cities to groups.
- **KP4**: Remove cities from groups.
- KP3 and KP4 can be used to multicast messages to a subset of controllers.

King's Page 5 (KP5)

- Specify an **action/reaction pair**.
- When a particular message is received or when a particular event occurs, a particular message can be sent or a particular event can be generated in response.

King's and Mayor's Pages

king's pages

Page 0 Start/Stop, Modes

Page 1 Base Number, Response Request

Page 2 Assign Envelopes

Page 3 Assign Groups

Page 4 Remove Groups

Page 5 Action Page - Reaction Page.

Page 8 Bit timing registers setting.

Page 9 New City physical address.

Page 10 Time Elapse.

Page 11 Circular Time Base Setup Page.

Page 12 Repetition Rate and Open Window Setup Page.

Page 16 Assign Documents to Folders.

Page 17 Create Documents, Forms or Lines from Lists.

Page 18 Create Compressed Letters.

Page 20 Create Filters for a Postmaster.

Block Transfer.

Time Herald.

mayor's pages

Page 1 EAN/UPC Code

Page 2 Serial Number

- Red = mandatory
- Black = optional

KVASER

Notes

- Each city must have a unique city number so the King can address a specific city.
- By default city number 0 denotes all cities.
- Folders 0 and 1 are predefined:
  - Folder 0 contains the King's document.
  - Folder 1 contains the Mayor's document.
- At startup each city adds a Base Number to its city number and announces itself on the bus.
  - E.g., city 5 could announce 256 + 5 = 261.
  - If the Base Number is 0, the city will remain silent.

Example Using CAN King 4.0

Install PC CAN Drivers – kvaser_drivers_setup.exe (Win7),
kvaser_w2k_xp.exe (older).

Install CAN King 4.0 – kvaser_canking_setup.exe (Win 7),
ck40std.exe (older).

Install Example City - ckdemo.zip.

All files are available in the public directory and also available from Kvaser: http://www.kvaser.com/support/downloads/

King's Pages Sent To City 5

- KP0 – set city mode: 0 8 5 0 1 3 0 0 0 0
  - CAN ID: 0
  - LEN: 8
  - Data[0]: City Number: 5
  - Data[1]: King's Page Number: 0
  - Data[2]: Action Mode: 1 = run
  - Data[3]: Communication Mode: 3 = communicate
  - Data[4-7]: Reserved (filler): 0

King's Pages Sent To City 5

- KP1 – set city's base number and request a response from the mayor: 0 8 5 1 0 0 0 1 0 0
  - CAN ID: 0
  - LEN: 8
  - Data[0]: City Number: 5
  - **Data[1]: King's Page Number: 1**
  - Data[2]: Mayor's Page Requested (FF=none): 0
  - Data[3]: Reserved (Zero): 0
  - Data[4-7]: Base Number (LSB to MSB): 0 1 0 0 = 256
  - Note: Mayor responds with MP0, CAN ID = 256+5 = 261

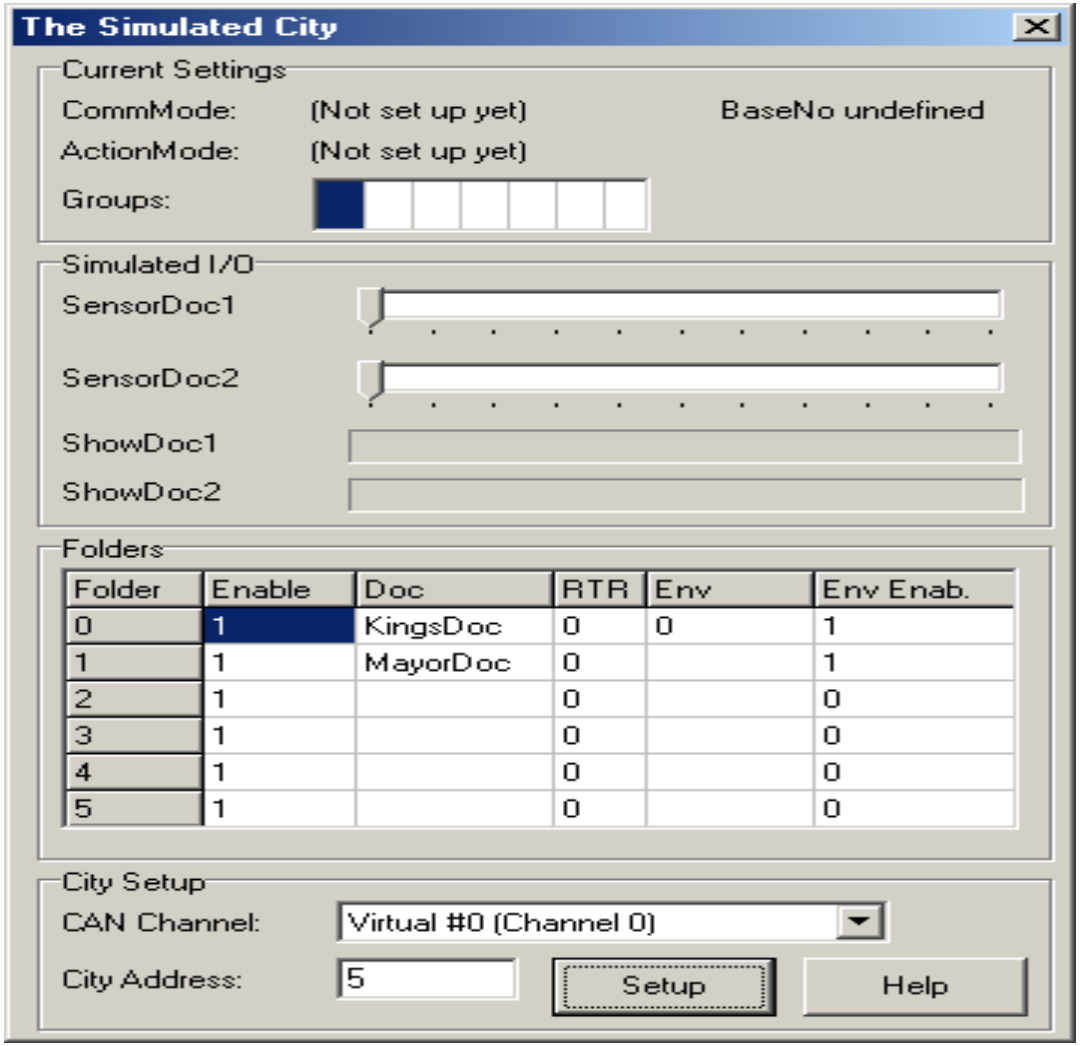
King's Pages Sent To City 5

- KP16 – assign a document to a folder and enable the folder: 0 8 5 16 2 129 240 0 1 0
  - **CAN ID: 0**
  - **LEN: 8**
  - **Data[0]: City Number: 5**
  - **Data[1]: King's Page Number: 16**
  - **Data[2]: Folder Number: 2**
  - **Data[3]: RTR (R=1) and DLC: 1R00DLC(4): 10000001 = 129**
  - **Data[4]: Enable (E=1), Remove Previous (R=1), Insert Doc (N=1), Rx/Tx (D=0 – recv, D=1 – tx):1ERN000D: 11110000 = 240**
  - **Data[5]: Document List Number: 0**
  - **Data[6]: Record Number: 1 (Read Document RD0.1)**
  - **Data[7]: Reserved: 0**

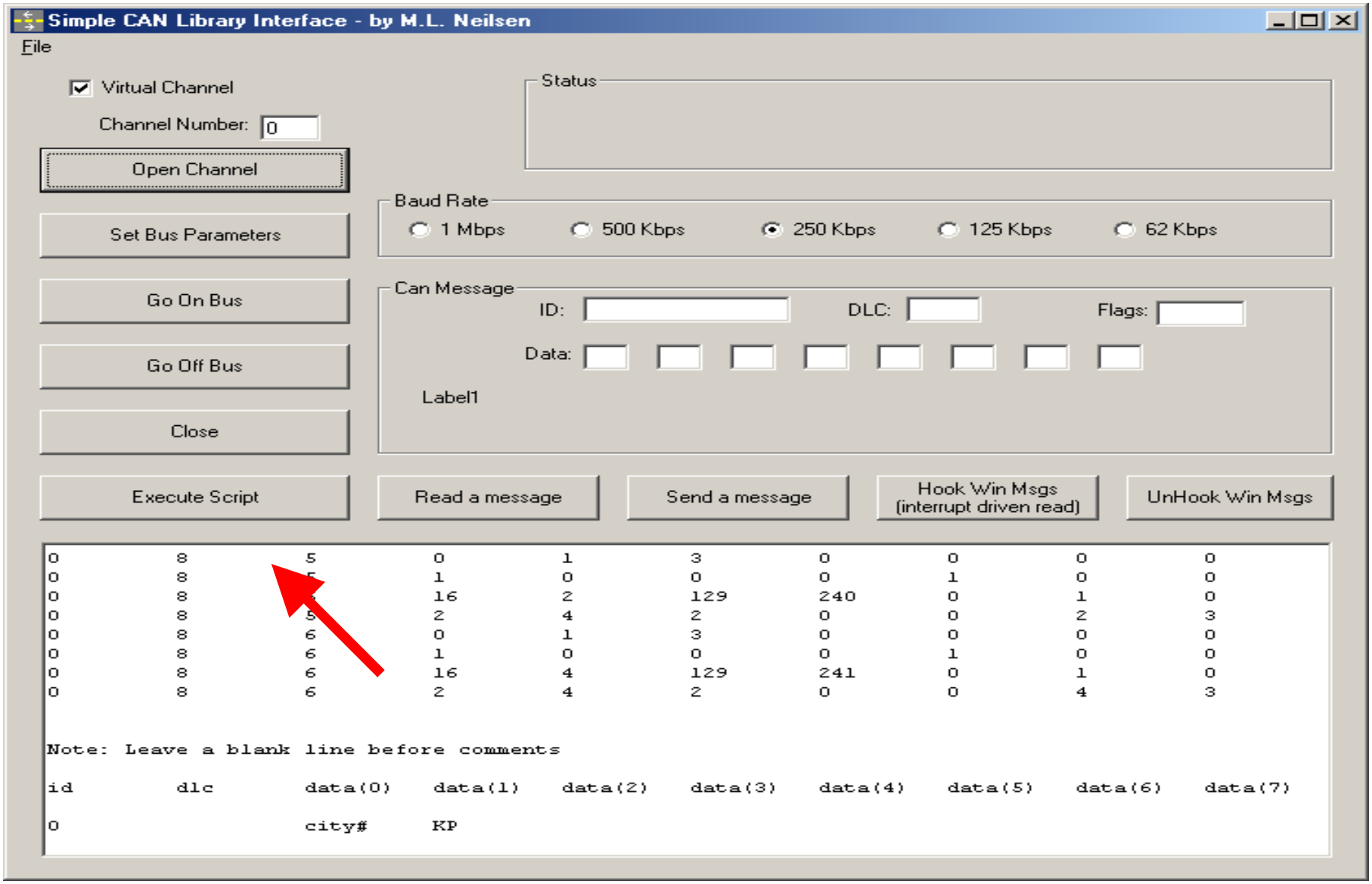
King's Pages Sent To City 5

- KP2 – assign a document to a folder and enable the folder: 0 8 5 2 4 2 0 0 2 3
  - **CAN ID: 0**
  - **LEN: 8**
  - **Data[0]: City Number: 5**
  - **Data[1]: King's Page Number: 2**
  - **Data[2-5]: Envelope Number (LSB to MSB): MSB = EC0xxxxx, E=1 – extended ID, C=1 – compressed env.: 4 2 0 0 = 0x204 = 516**
  - **Data[6]: Folder Number**
  - **Data[7]: Assign/Enable Folder 000000AE: 3 = assign and enable**

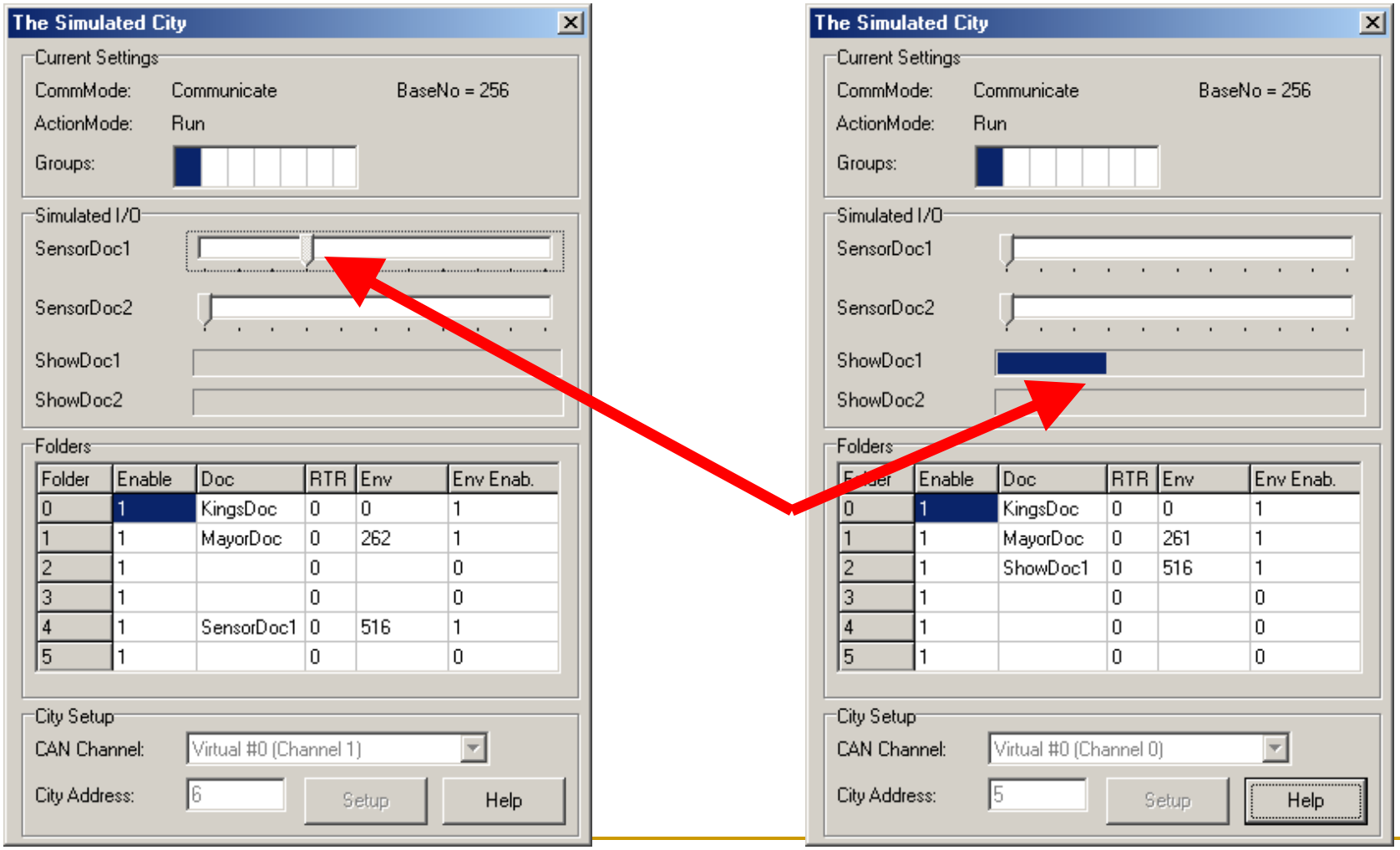
CANKing Demo (CKDemoTurin.exe)



CAN Library Interface (vb6test.exe)



Example


The Simulated City
Current Settings
CommMode: Communicate
BaseNo = 256
ActionMode: Run
Groups:
Simulated I/O
SensorDoc1
SensorDoc2
ShowDoc1
ShowDoc2
Folders
Folder | Enable | Doc | RTR | Env | Env Enab.
0 | 1 | KingsDoc | 0 | 0 | 1
1 | 1 | MayorDoc | 0 | 262 | 1
2 | 1 | | 0 | | 0
3 | 1 | | 0 | | 0
4 | 1 | SensorDoc1 | 0 | 516 | 1
5 | 1 | | 0 | | 0
City Setup
CAN Channel: Virtual #0 (Channel 1)
City Address: 6
Setup
Help
The Simulated City
Current Settings
CommMode: Communicate
BaseNo = 256
ActionMode: Run
Groups:
Simulated I/O
SensorDoc1
SensorDoc2
ShowDoc1
ShowDoc2
Folders
Folder | Enable | Doc | RTR | Env | Env Enab.
0 | 1 | KingsDoc | 0 | 0 | 1
1 | 1 | MayorDoc | 0 | 261 | 1
2 | 1 | ShowDoc1 | 0 | 516 | 1
3 | 1 | | 0 | | 0
4 | 1 | | 0 | | 0
5 | 1 | | 0 | | 0
City Setup
CAN Channel: Virtual #0 (Channel 0)
City Address: 5
Setup
Help

Higher Layer CAN Protocols

- CAN Kingdom (Kvaser)
- **SAE J1939**
- ODVA DeviceNet
- Honeywell Smart Distributed System (SDS)

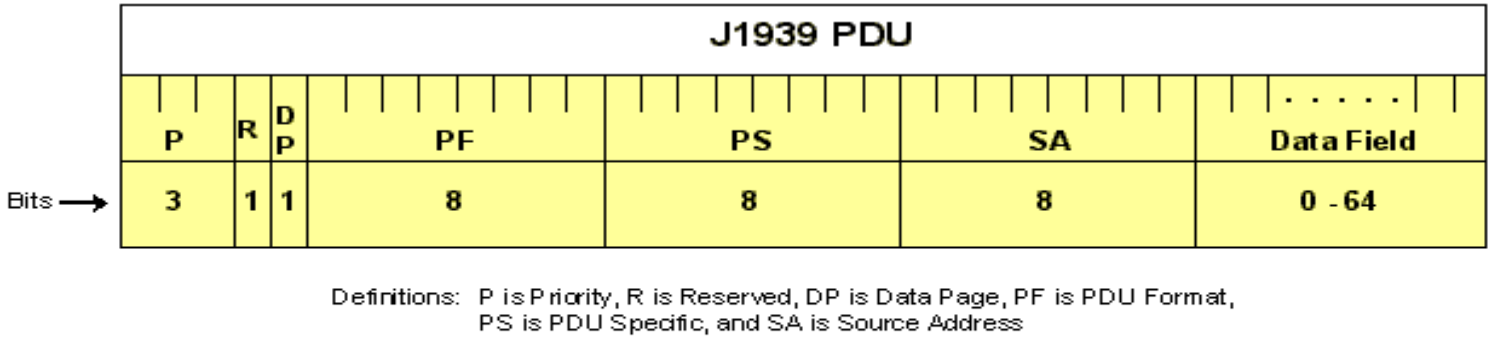
SAE J1939

- SAE J1939 was designed to allow electronic devices from different vendors to communicate with each other through a standard architecture.
- Only data frames are transmitted at a bit rate of 250 Kbps.
- Most CAN identifiers are defined by the standard.
- This results in system performance that may be far below the capability of CAN.

J1939 in OSI Reference Model

- J1939/11 - Physical Layer - twisted pair, twisted quad, ...
- J1939/21 - Data Link Layer - define frame (Protocol Data Unit (PDU)) format, point-to-point and broadcast (BLAST) protocols
- J1939/31 - Network Layer
- J1939/71 - Application Layer
- J1939/81 - Network Management
- J1939/0* - General documentation:
  - 01 - Truck and Bus
  - 02 - Agricultural Equipment
  - ...

J1939 Protocol Data Unit



- The CAN 29-bit identifier is broken up into:
  - Priority (3 bits)
  - Reserved Bit (1 bit)
  - Data Page (1 bit)
  - PDU (Protocol Data Unit) Family (PF) (8 bits)
  - PDU Specific (PS) (8 bits)
  - Source Address (SA) (8 bits)

Higher Layer CAN Protocols

- CAN Kingdom (Kvaser)
- SAE J1939
- **ODVA DeviceNet**
- **Honeywell Smart Distributed System (SDS)**

ODVA DeviceNet (DN)

- ODVA Organization (Allen-Bradley, ...)
- Predefined Master/Slave connections and message identifiers
- Used for networking low-level Programmable Logic Controllers (PLC) for industrial automation
- Based on CAN 2.0A (11-bit identifiers)
- A wide range of products from more than 270 vendors

Smart Distributed System (SDS)

- Honeywell standard based on CAN
- CAN identifier is related to node (host) identifier
- PC alternative to PLC
- A wide range of modules from 50 vendors
- SDS CAN identifier (short CAN 2.0A form):
  - Direction (1 bit) - Host to Guest or Guest to Host
  - Device Address (7 bits) - Host Identifier
  - PDU Type (3 bits) - 0 = change state to off, 1 = change state to on, 2 = off ack, 3 = on ack, 4 = write off, 5 = write on, 6 = write off ack, 7 = write on ack.

Mixing Higher Layer Protocols

- For CAN Modules to co-exist on the same bus, they must:
  - use the same bit rate
  - use the same physical medium
  - use compatible, unique CAN identifiers
- Bit rates supported:
  - 1Mbps: CK, SDS
  - 500Kbps: CK, SDS, DN, CANopen
  - 250Kbps: CK, SDS, DN, J1939, NMEA2000
  - 125Kbps: CK, SDS, DN

Time-Triggered vs. Event-Triggered

- Time-triggered control system
  - All activities are carried out at certain points in time know a priori.
  - All nodes have a common notion of time, based on approximately synchronized clocks.
- Event-triggered control system
  - All activities are carried out in response to relevant events external to the system.

Time-Triggered Protocols

- Using Hardware and Software
  - TTCAN - Time-Triggered CAN
  - TTP/C - Time-Triggered Protocol (Vers. C)
- Using Software
  - TTP/A - Time-Triggered Protocol (Vers. A)
  - Time Herald in CAN Kingdom

Summary

- Next Time:
  - Other Higher-Level CAN Protocols
  - Time-Triggered Protocols