Intra-Vehicular Wireless Sensor Networks

Sinem Coleri Ergen
(joint with Yalcin Sadi, C. Umit Bas)
Wireless Networks Laboratory,
Electrical and Electronics Engineering,
Koc University

Outline

- Motivation for Intra-Vehicular Wireless Sensor Networks
- Medium Access Control Layer
- Inter-vehicular networks

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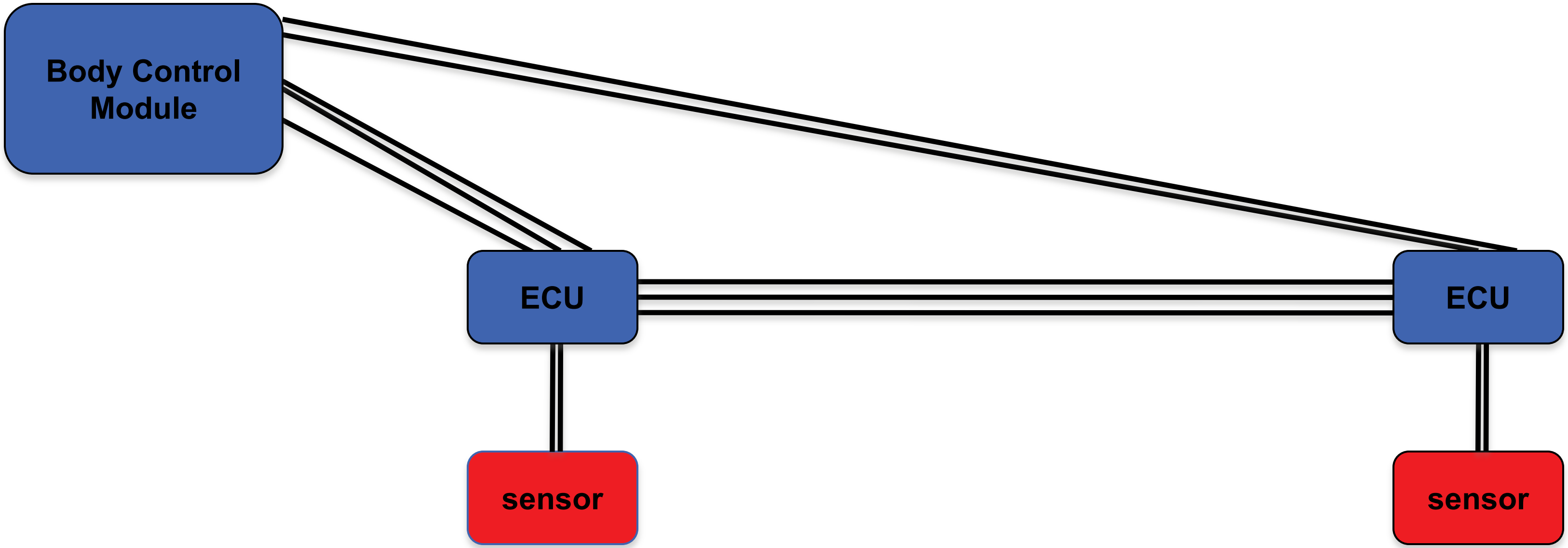
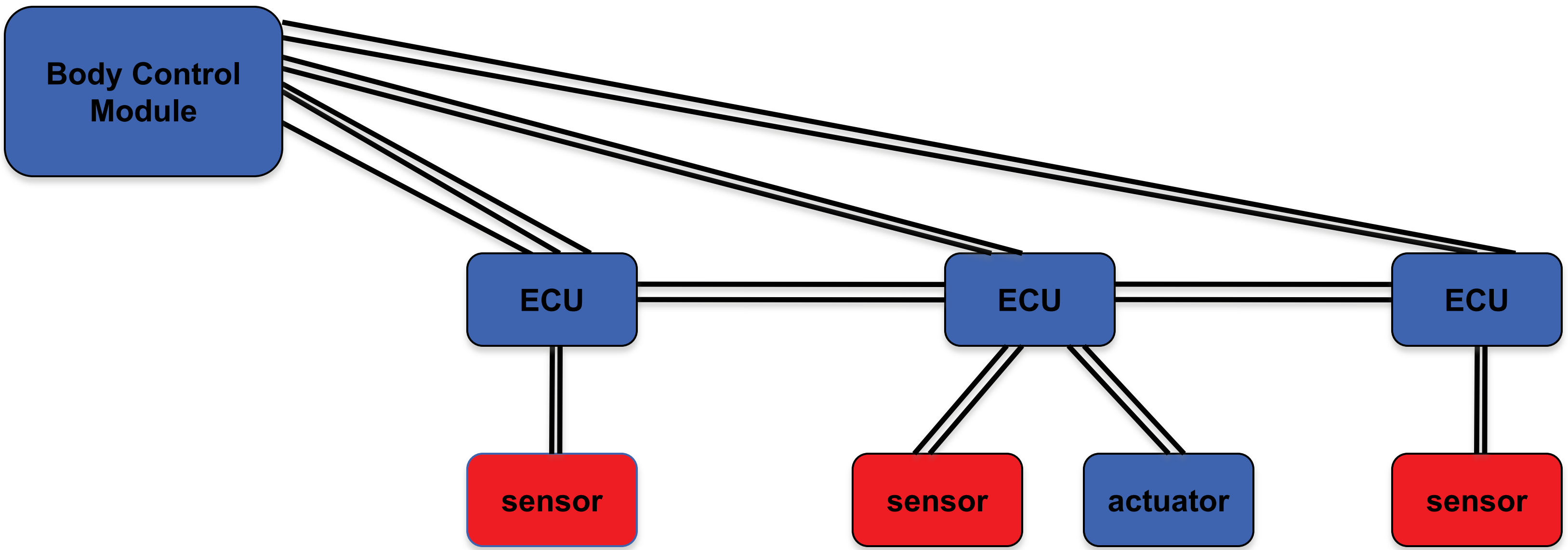
History of In-Vehicle Networking

- Early days of automotive electronics
  - Each new function implemented as a stand-alone ECU, subsystem containing a microcontroller and a set of sensors and actuators
  - Data exchanged between point-to-point links



History of In-Vehicle Networking

- In the 1990s
  - Increase in the number of wires and connectors caused weight, cost, complexity and reliability problems
  - Developments in the wired communication networks



History of In-Vehicle Networking

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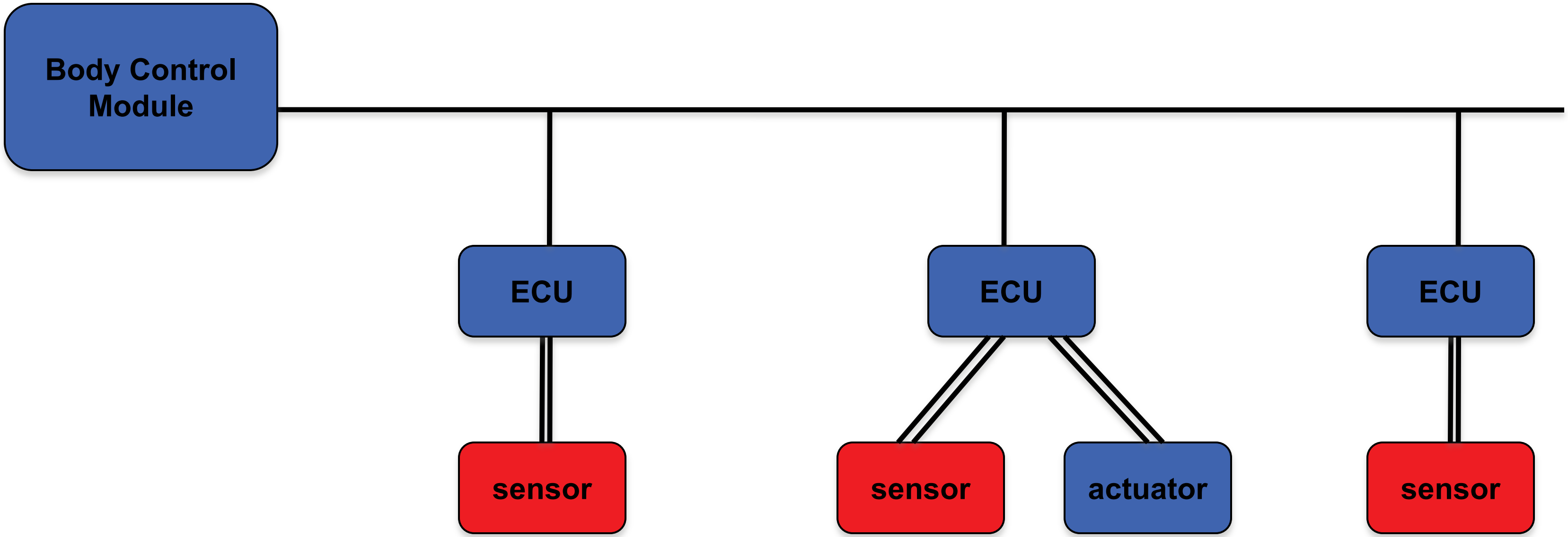
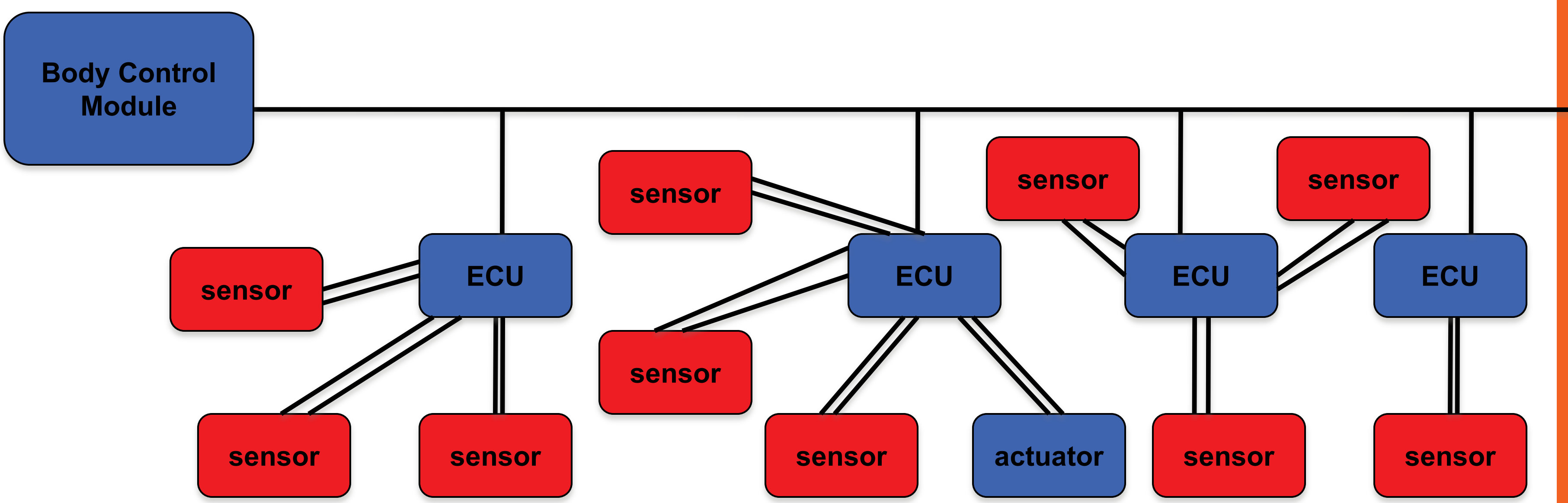
  - Multiplexing communication of ECUs over a shared link called bus



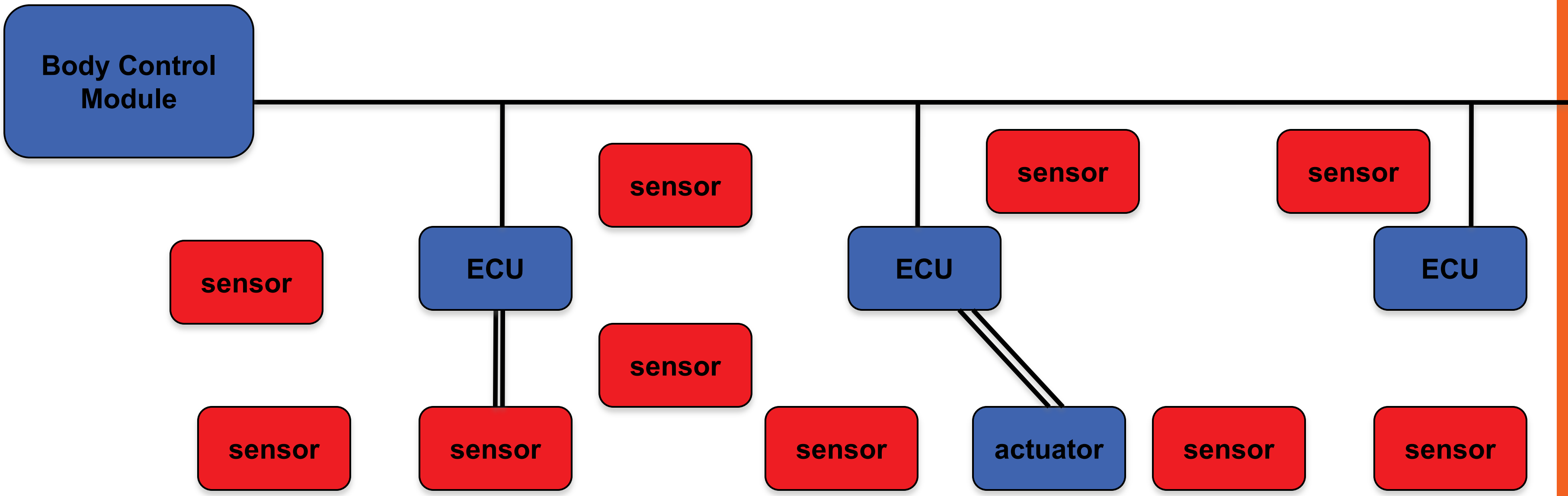
History of In-Vehicle Networking

- Today
  - Increases in number of sensors as electronic systems in vehicles are replacing purely mechanical and hydraulic systems causes weight, cost, complexity and reliability problems **due to wiring**
  - Advances in low power wireless networks and local computing



History of In-Vehicle Networking

- Today
  - Increases in number of sensors as electronic systems in vehicles are replacing purely mechanical and hydraulic systems causes weight, cost, complexity and reliability problems **due to wiring**
  - Advances in low power wireless networks and local computing
  - Intra-Vehicular Wireless Sensor Networks (IVWSN)

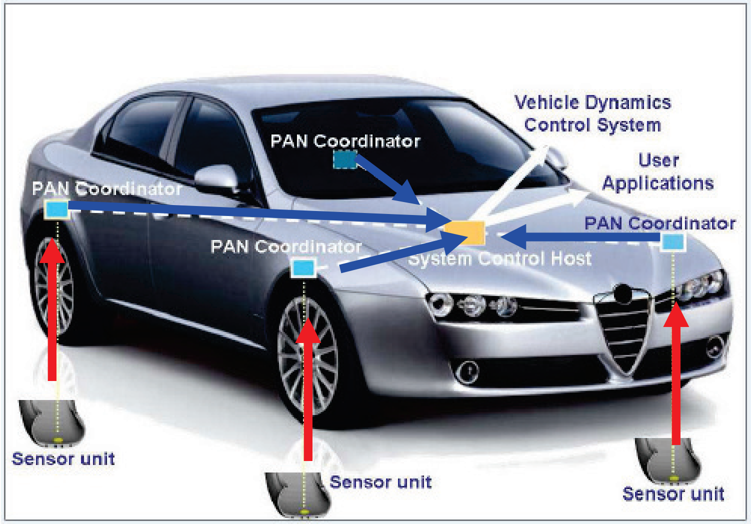


First IVWSN Example: Intelligent Tire

Active Safety Systems

•Change the behavior of vehicle in pre-crash time or during the crash event to avoid the crash altogether

•Examples: Anti-lock Braking System (ABS), Traction Control System (TCS), Electronic Stability Program (ESP), Active Suspension System



Requires accurate and fast estimation of vehicle dynamics variables

•Forces, load transfer, actual tire-road friction, maximum tire-road friction available

Enable a wide range of new applications

On-board sensors + indirect estimation

Intelligent Tire

•More accurate estimation

•Even identify road surface condition in real-time

S. C. Ergen, A. Sangiovanni-Vincentelli, X. Sun, R. Tebano, S. Alalusi, G. Audisio and M. Sabatini, "The Tire as an Intelligent Sensor", IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, vol.28, no.7, pp.941-955, July 2009..

IVWSN: Distinguishing Characteristics

- Tight interaction with control systems
  - Sensor data used in the real-time control of mechanical parts in different domains of the vehicles
- Very high reliability
  - Same level of reliability as the wired equivalent
- Energy efficiency
  - Remove wiring harnesses for both power and data
- Heterogeneity
  - Wide spectrum for data generation rate of sensors in different domains
- Harsh environment
  - Large number of metal reflectors, a lot of vibrations, extreme temperatures
- Short distance
  - Maximum distance in the range 5m-25m

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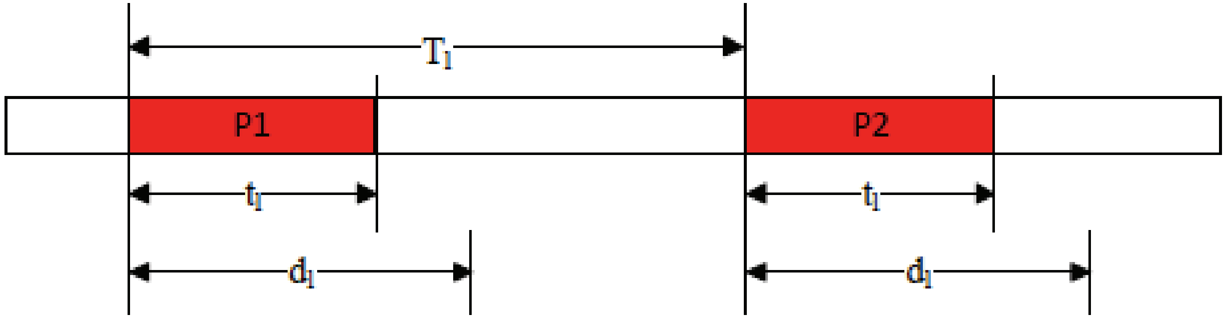
Medium Access Control Layer: System Requirements

- Most of the packets generated periodically
  - Network Control Systems (NCS): sensor data -> real-time control of mechanical parts
  - Packet generation period, transmission delay and reliability requirements determined by NCS analysis (T_l, d_l, r_l)

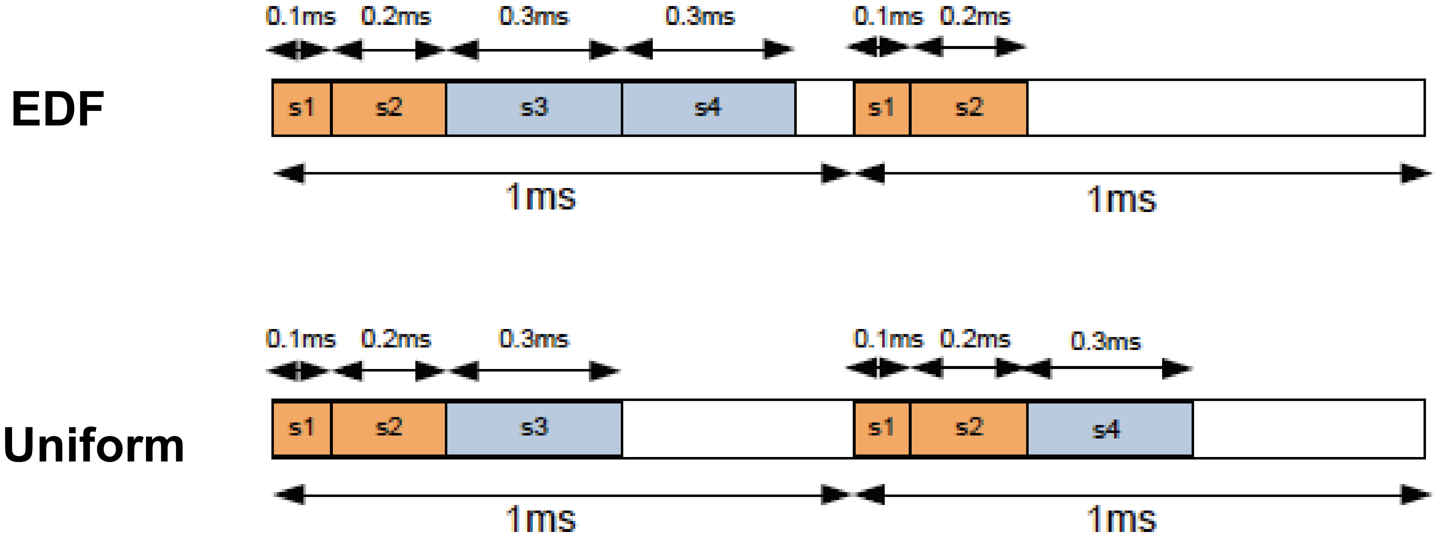


- Aperiodic packets generated rarely

Medium Access Control Layer: System Requirements

- Adaptivity and robustness requirement
  - Nodes should be scheduled as uniformly as possible
    - Allocate aperiodic packets
    - Reschedule lost packets

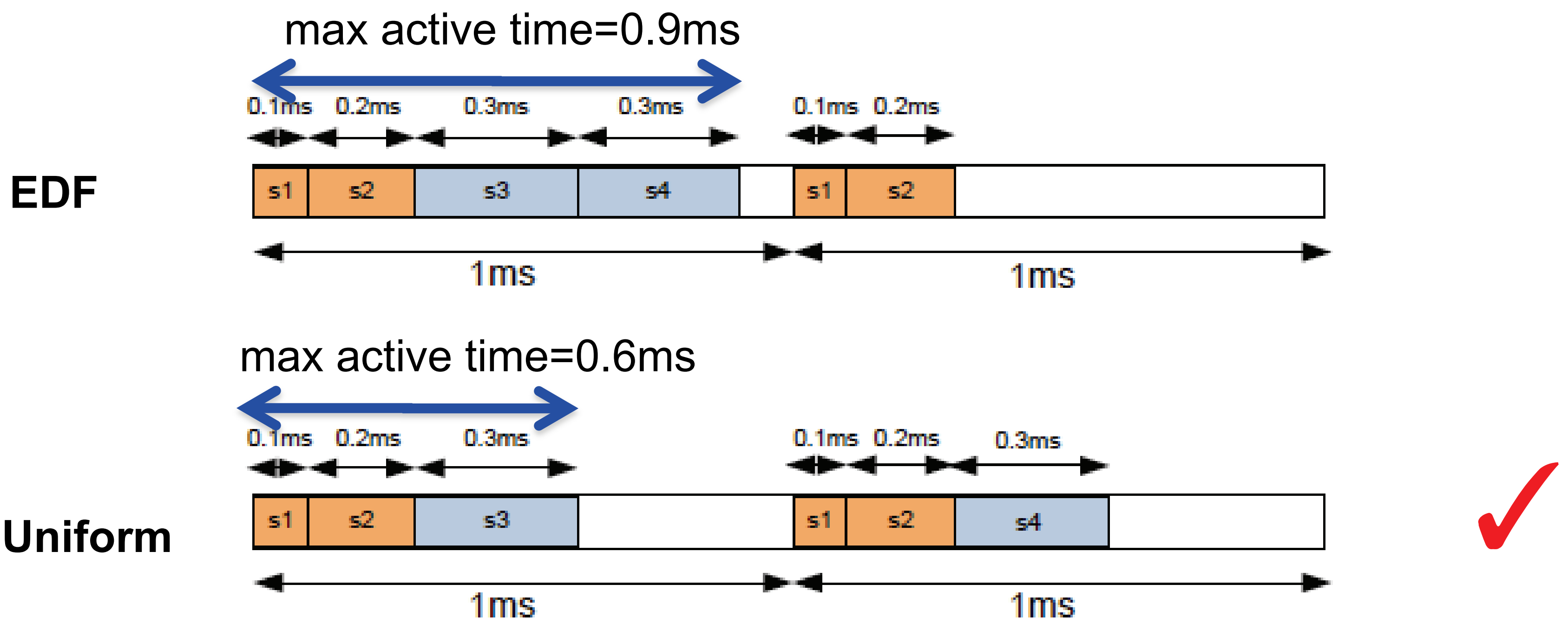
Let us assume that we have 2 sensors of transmission delay $t_1 = 0.1ms$ and $t_2 = 0.2ms$ and packet sending period $T_1 = T_2 = 1ms$, and 2 sensors of transmission delay $t_3 = t_4 = 0.3ms$ and packet sending period $T_3 = T_4 = 2ms$.



Medium Access Control Layer: System Model

- (T_l, d_l, r_l) given for each link l
- $T_1 \le T_2 \le \ldots \le T_L$
- Choose subframe length as T_1 for uniform allocation
- Assume $T_i / T_1 = s_i$ is an integer: Allocate every s_i subframes

- **Uniform distribution $\equiv$ minimize max subframe active time**



Medium Access Control Layer: One ECU

minimize

$$\max_{j\in[1,M]} \sum_{i=1}^{L} a_{ij} t_i$$ ← Maximum active time of subframes

subject to

$$\sum_{j=k}^{k+s_i-1} a_{ij} = 1 \quad \textbf{for} \quad k \in [1, M - s_i + 1], i \in [1, L]$$ ← Periodic packet generation

$$t_i \le d_i \quad \textbf{for} \quad i \in [1, L]$$ ← Delay requirement

$$t_i (p_i + p_{tx} + p_{rx}) \le e_i \quad \textbf{for} \quad i \in [1, L]$$ ← Energy requirement

$$p_i \le p_{max} \quad \textbf{for} \quad i \in [1, L]$$ ← Maximum allowed power by UWB regulations

$$t_i = \frac{L_i}{x_i} \quad \textbf{for} \quad i \in [1, L]$$ ← Transmission time

$$x_i \le \frac{p_i h_{ii}}{SINR_i^{thr} \left(\frac{N_0}{2}\right)} \textbf{for} \quad i \in [1, L]$$ ← Transmission rate of UWB for no concurrent transmission case

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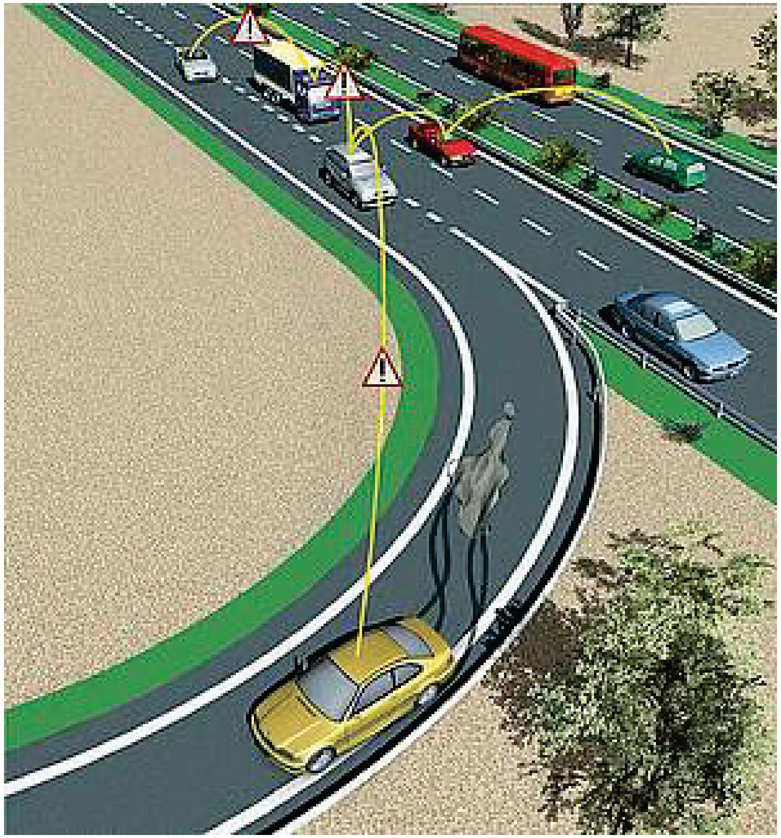
Inter-Vehicular Communication (IVC) Networks



- Safety applications
  - Emergency situations such as accidents, icy road
  - Require guaranteed delivery of data
- Up to now, satisfying these guarantees with random access protocols such as IEEE 802.11p protocol
- Investigate heterogeneous usage of LTE and IEEE 802.11p in providing more robust communication

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Thank You!

Sinem Coleri Ergen: sergen@ku.edu.tr

Personal webpage: http://home.ku.edu.tr/~sergen

Wireless Networks Laboratory: http://wnl.ku.edu.tr