NOTICE: An Architecture for the Notification of Traffic Incidents

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Outline

- Introduction
- Overview of NOTICE
- The wireless communication system
- Analyzing vehicle-to-belt communication
- Simulation results
- Concluding remarks

Motivation

Give drivers advance notification of upcoming traffic congestion

From trekearth.com

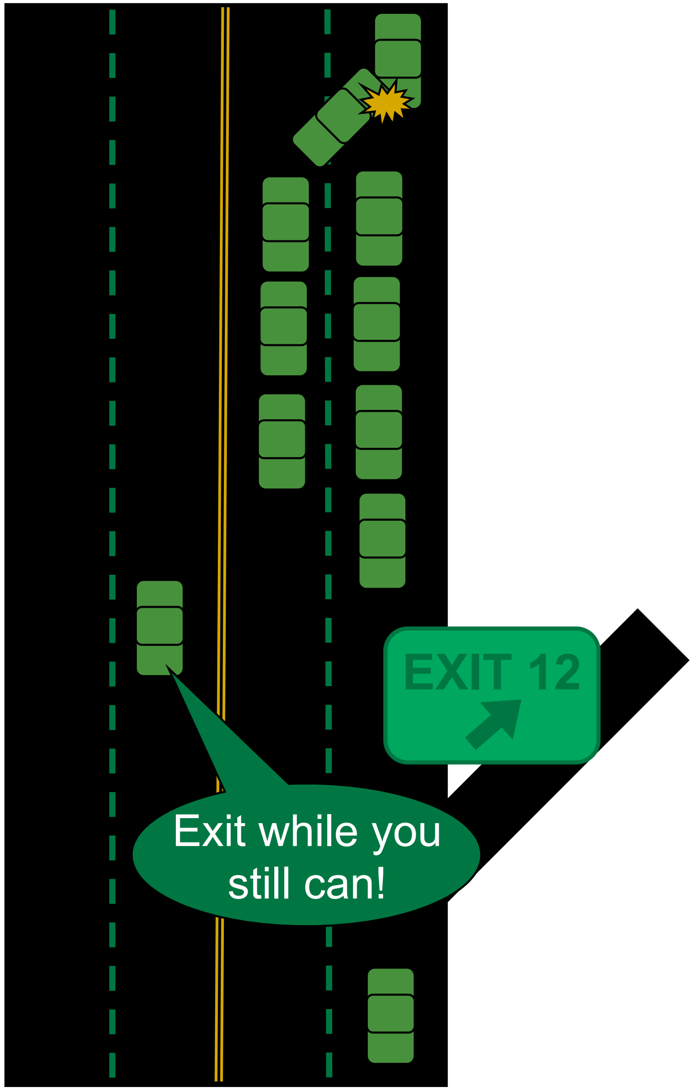
1. Introduction

- Road safety is a growing concern for governments around the world
  - in 2006* in the U.S. alone 5,973,000 collisions were reported in which 42,642 people were killed or about 5 people died every hour
- Traffic congestion comes with a huge price tag
  - in 2006* in the U.S. 3.6 billion work-hours wasted, 5.7 billion gallons of fuel wasted

*National Highway Traffic Safety Administration (NHTSA) report (March 2008)

1. Introduction

Traffic incident notification can help prevent or mitigate the effect of traffic events by alerting drivers and by giving them time to take alternative routes



1. Introduction

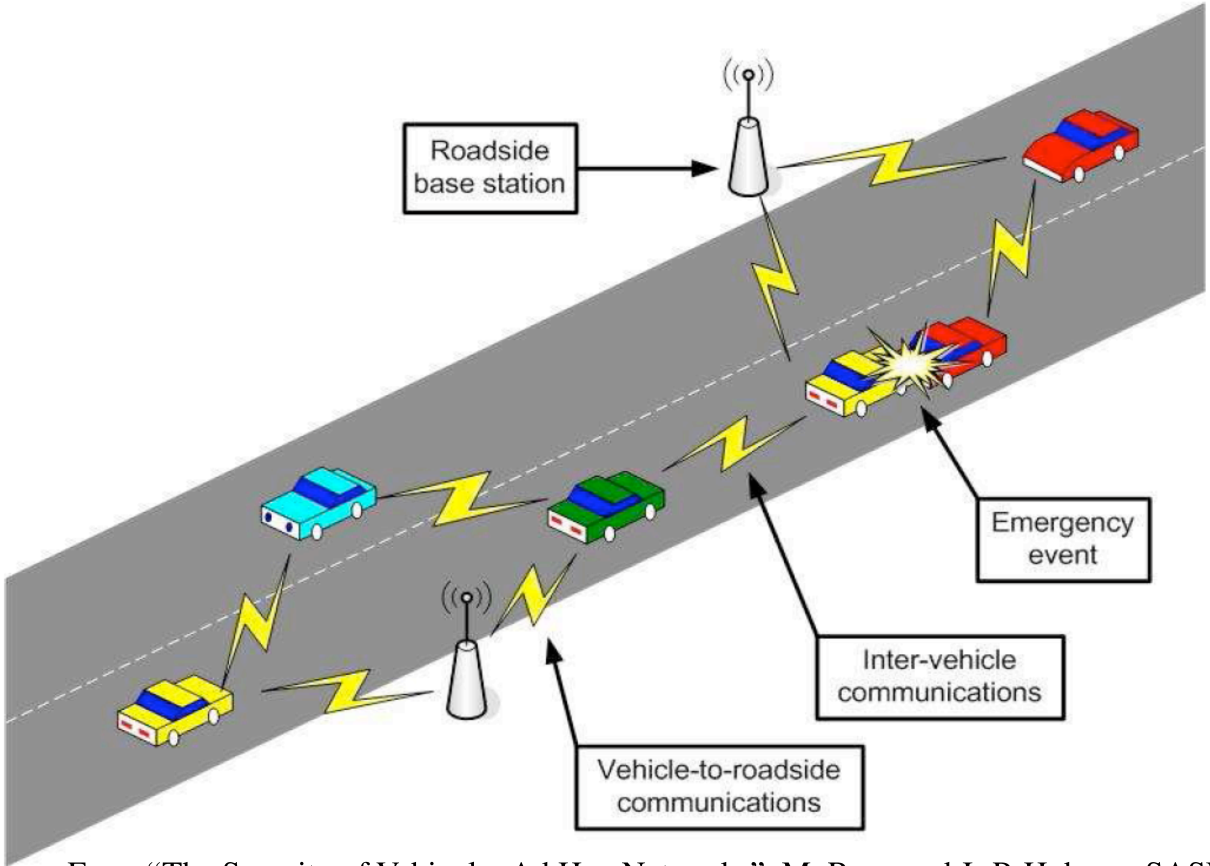
- Original impetus for VANET
  - road-safety applications
  - traffic advisories
  - congestion info
  - delays and detours
- Later concerns
  - security
  - privacy
- More recent infotainment applications
  - peer-to-peer applications
  - location-specific services
  - gaming

1. Introduction

- Vehicular Ad-hoc Networks (VANET) have merged with Intelligent Transportation Systems
  - to improve traffic safety and reduce congestion
  - communications: vehicle-to-vehicle (V2V) and/or vehicle-to-infrastructure (V2I)

1. Introduction

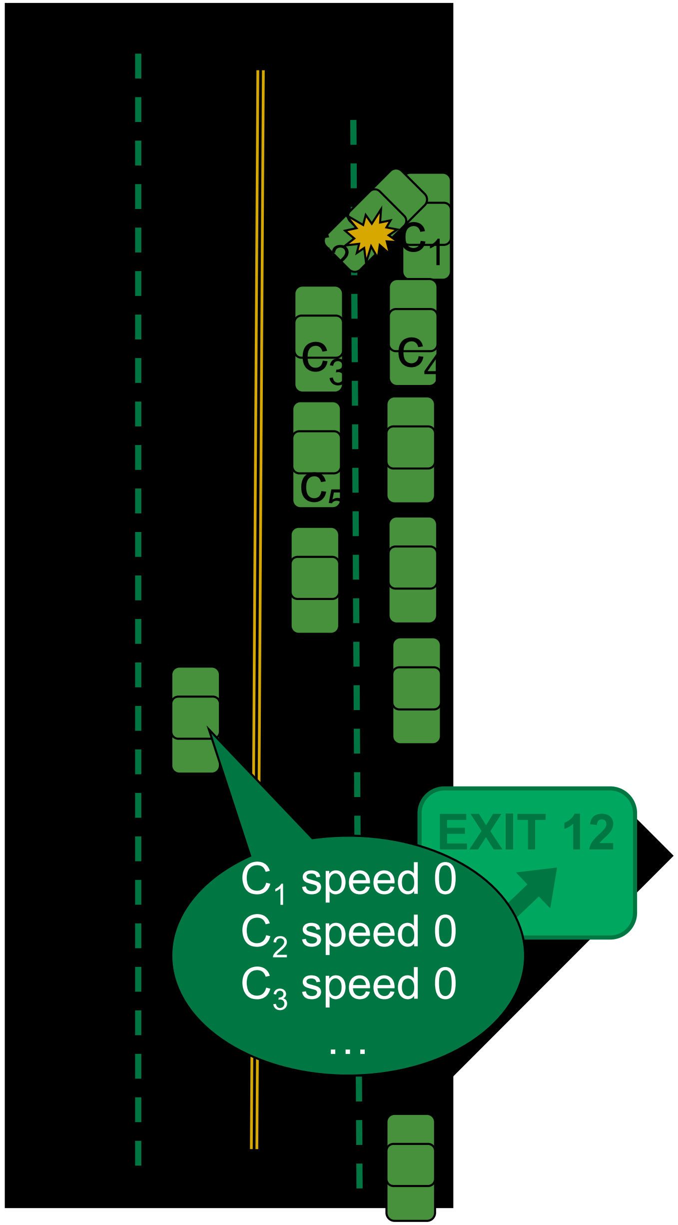
Illustrating V2V and V2I communications



From “The Security of Vehicular Ad Hoc Networks”, M. Raya and J.-P. Hubaux, SASN 2005

1. Introduction

- Traffic information
  - cars report their position and speed to surrounding cars
  - cars may suggest alternate routes
- Weather warnings
- Road conditions
- Collision warning
- Congestion warning
- Intersection assistance



2. Overview of NOTICE

- The NOTICE system has been proposed recently for **NO**tification of **T**raffic **I**ncidents and **C**ong**E**stion
  - aims to provide automated notification of traffic incidents on highways in order to reduce congestion and improve overall traffic safety
  - NOTICE is a V2I system featuring robust security and privacy mechanisms

2. Overview of NOTICE

- NOTICE works based on communication between vehicles and sensor belts embedded in the road
- Incident notification does not rely on direct reports from drivers and the vehicle identities are not disclosed
- The best physical layer for NOTICE is still an open issue

2. Overview of NOTICE

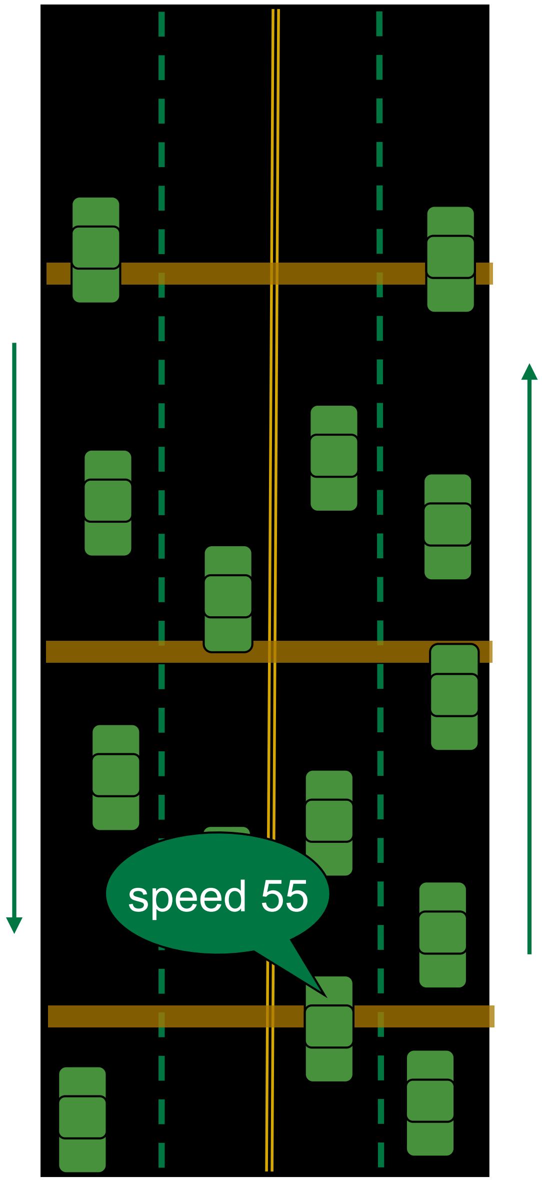
- The main goal of this talk is to provide insight into how NOTICE works
- We also discuss various parameters concerning successful communication between vehicles and sensor belts

2. Overview of NOTICE

- Vehicles are equipped with a tamper-proof Event Data Recorder (EDR)
  - records operating parameters of the vehicle such as speed, acceleration, position, and lane changes
  - optional traffic information keyed in by the driver such as road conditions, accidents/incidents, and so on

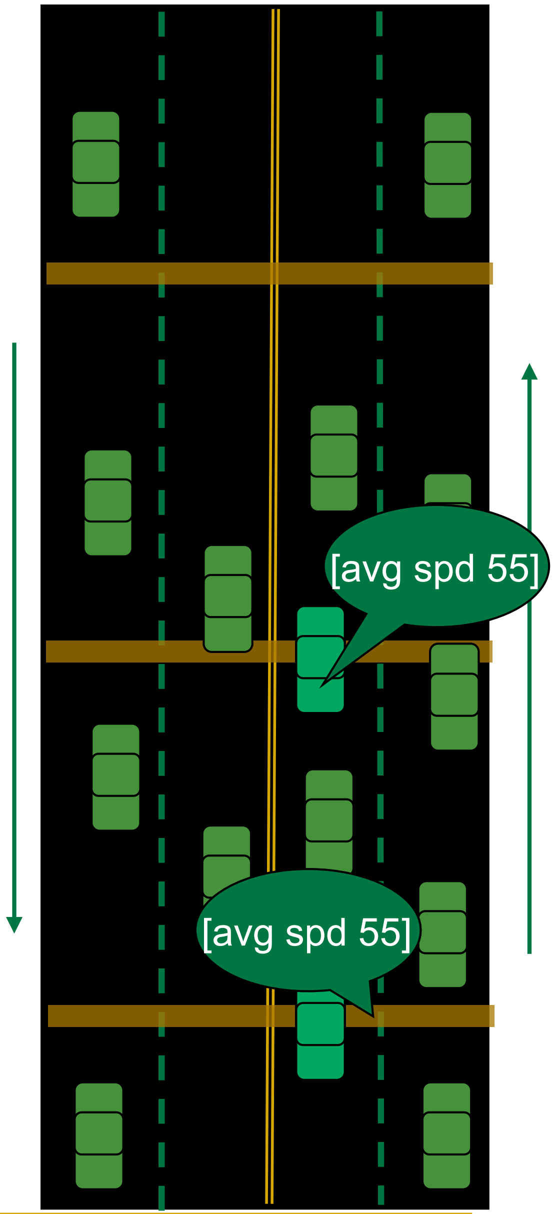
2. Overview of NOTICE

- Key philosophy: associate a message with a physical vehicle
- Embed intelligent sensor belts in the roadway
- When a car passes over the belt, its EDR reports to the belt
- The belt builds beliefs about traffic incidents by aggregating reports from passing cars and other belts



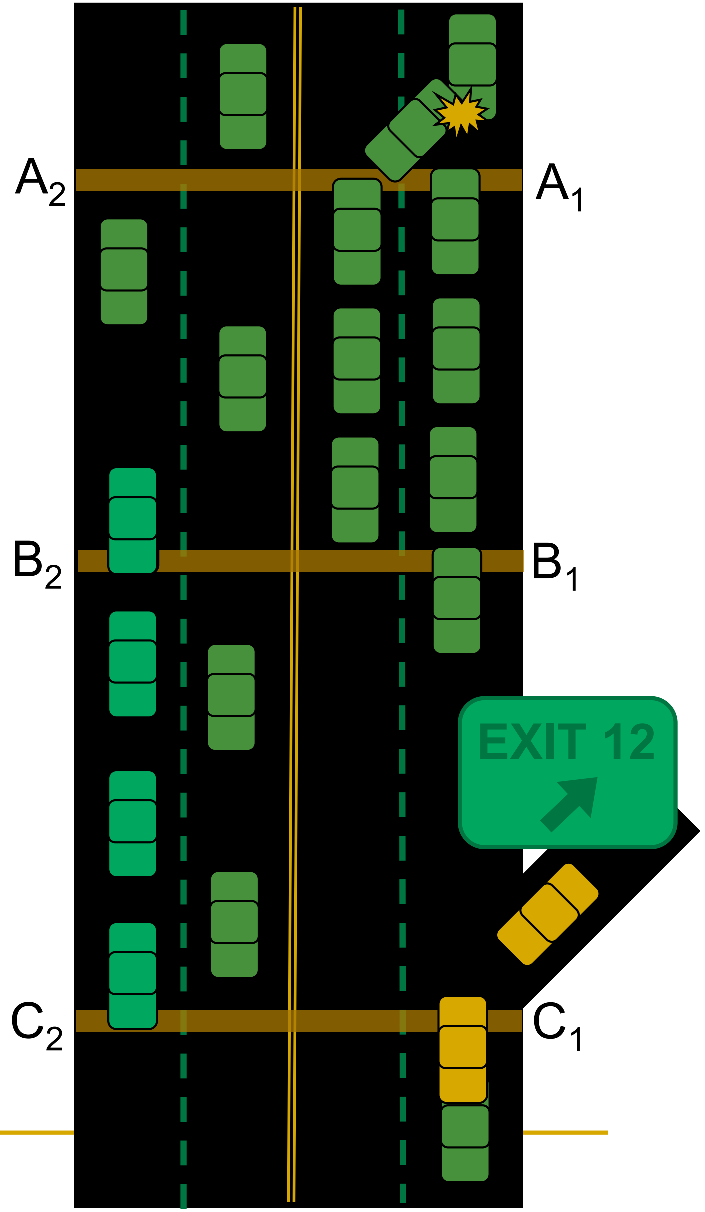
2. Overview of NOTICE

- Individual belt in each lane
- Connected belts (sub-belts) communicate instantaneously
- Non-connected belts do not directly communicate
  - use cars as data mules
- Belt gives encrypted message to a car to drop off at next belt



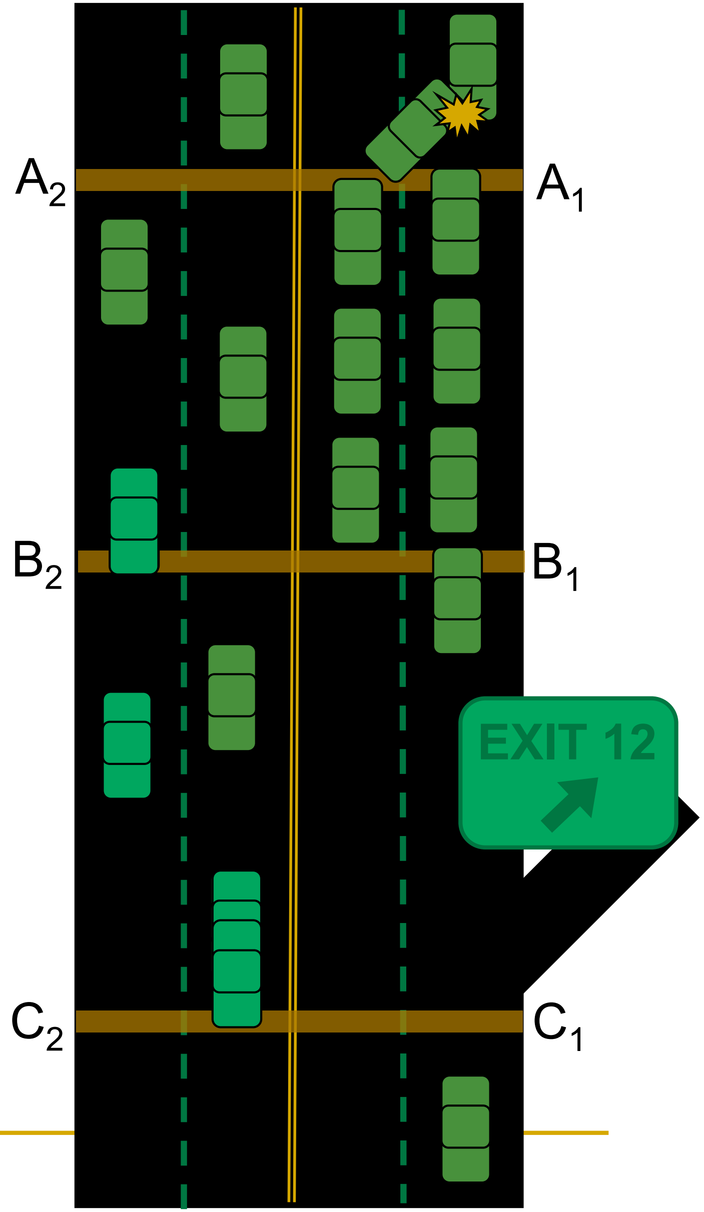
2. Overview of NOTICE

- B_1 is aware of traffic slowdown
  - creates encrypted message with latest traffic statistics
- Information is provided to B_2
- B_2 uploads message onto car destined for C_2
- When C_2 receives message, it provides it to C_1
- C_1 notifies passing cars



2. Overview of NOTICE

- B_2 uploads message with *urgent* bit set onto car destined for C_2
- Car broadcasts message to other cars for faster delivery
- Cars are passing encrypted messages, so no security risk

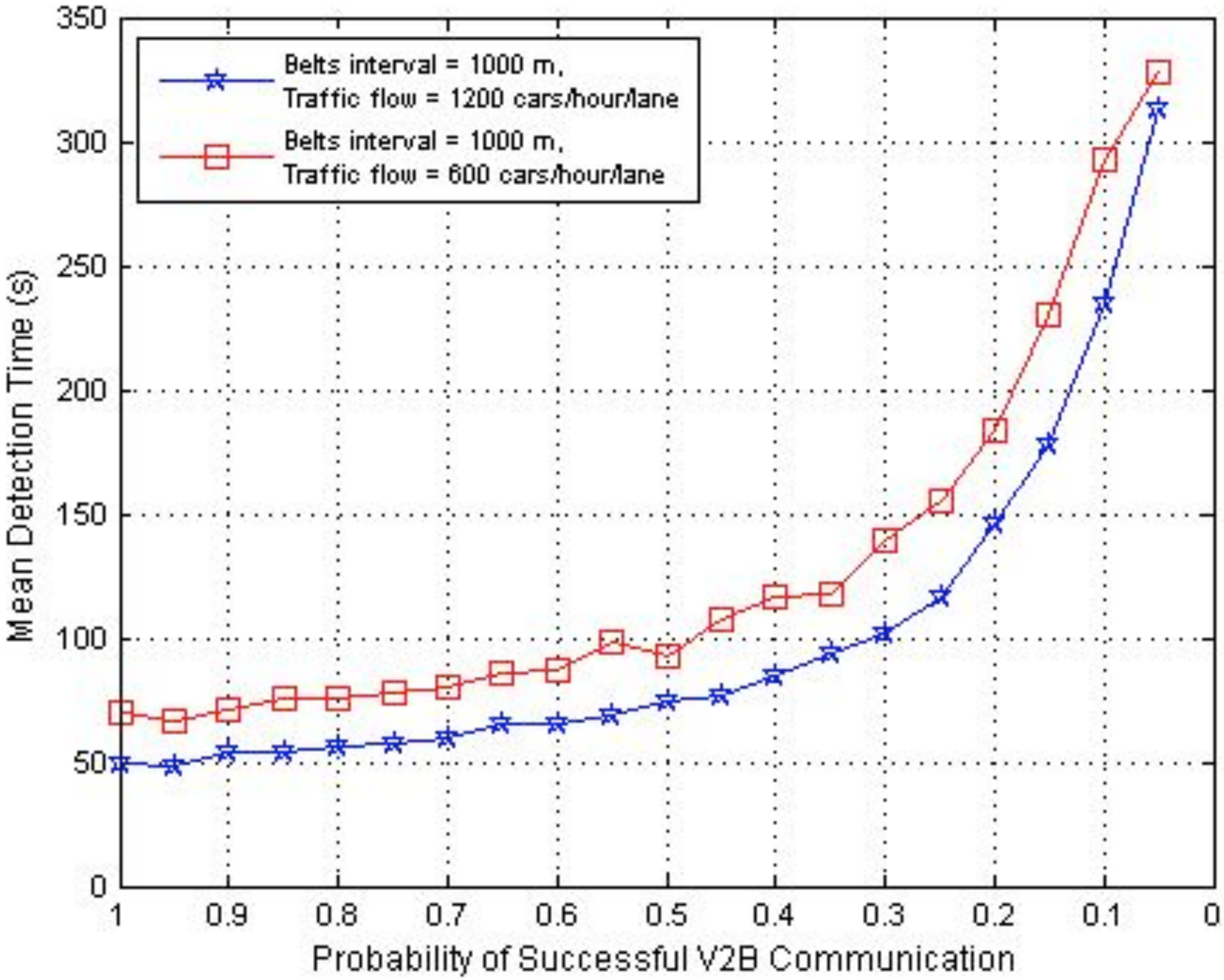


2. Overview of NOTICE

Incident detection time

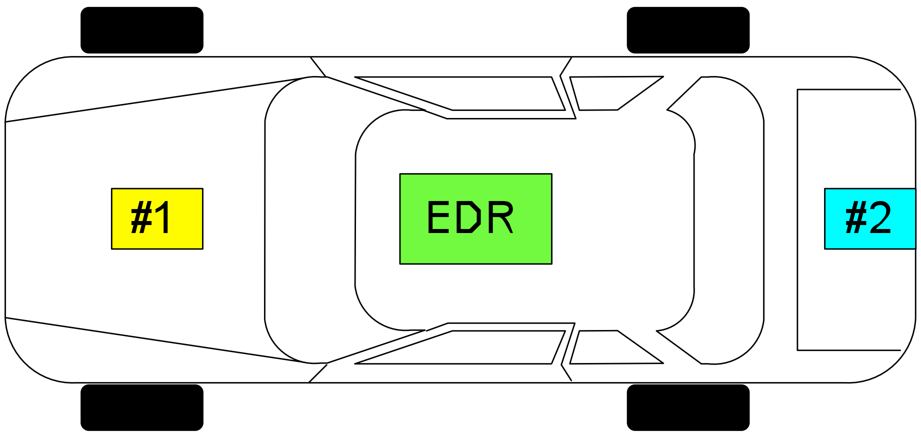
- defined as the time required by a belt to decide that a road incident has taken place
- vehicles traveling toward the incident area should be alerted as quickly as possible
- efficiency of the NOTICE incident notification relies on the incident detection time
- in practice, not all vehicle can successfully communicate with the sensor belts
- a highway incident can be detected in about 1 minute even when the NOTICE system has only 80% successful vehicle-to-belt communication

2. Overview of NOTICE



3. The wireless communication system

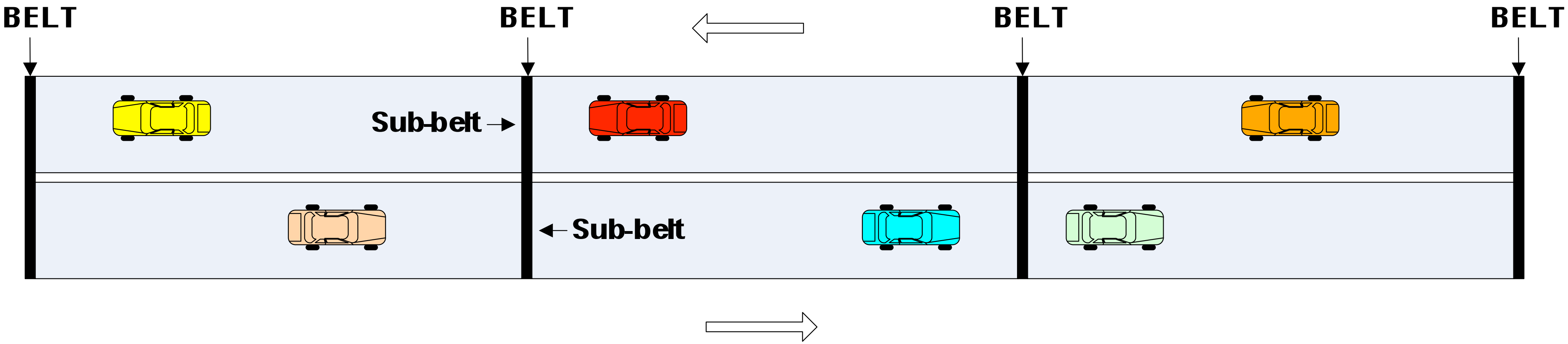
- EDR is also equipped with two wireless transceivers in order to exchange information with sensor belts in the roadway
  - these transceivers operate at low power in order to have short-range radiation and secure the vehicular communication



3. The wireless communication system

- On the road side
  - belts are embedded in the roadway every mile or so
  - a belt may have sub-belts, one for each traffic lane
  - each belt has a set of pressure sensors responsible for detecting vehicles passing over the belt and a set of wireless transceivers used for communicating with the passing vehicles

3. The wireless communication system



- each belt operates independently without wired or wireless infrastructure between belts
- sub-belts of the same belt on different sides of the road have wired connection embedded under median for direct communication

3. The wireless communication system

- Incident notification is based on communication between belts and passing cars
  - passing vehicles report/exchange traffic information with the belt they are passing
  - the belt makes incident and/or congestion inferences by accumulating a sufficient number of incident reports from passing vehicles
    - this mechanism helps exclude reports sent by malicious vehicles which may inject falsified information

3. The wireless communication system

Incident detection/notification involves the following communication modes:

- Vehicle-to-Belt communication
- Belt-to-Belt communication
- Vehicle-to-Vehicle communication

3. The wireless communication system

Vehicle-to-Belt communication

- communication between a sensor belt and a vehicle passing over it, consisting of two phases:
  - handshaking : transceiver #1 handshakes with the belt over which the vehicle is passing
  - data exchange: transceiver #2 exchanges traffic-related information with the belt
- in order to have successful vehicle-to-belt communication, handshaking must be established first followed by information exchange

3. The wireless communication system

Belt-to-Belt communication

- belts in the same driving direction communicate with each other indirectly through passing vehicles that carry information from a given belt to the next belt
- passing vehicles upload information received from previous belt to the current belt and/or download information from the current belt for the next belt, employing vehicle-to-belt communication
- direct communication between sub-belts is necessary when the belt needs to send notifications to other belts in backward direction

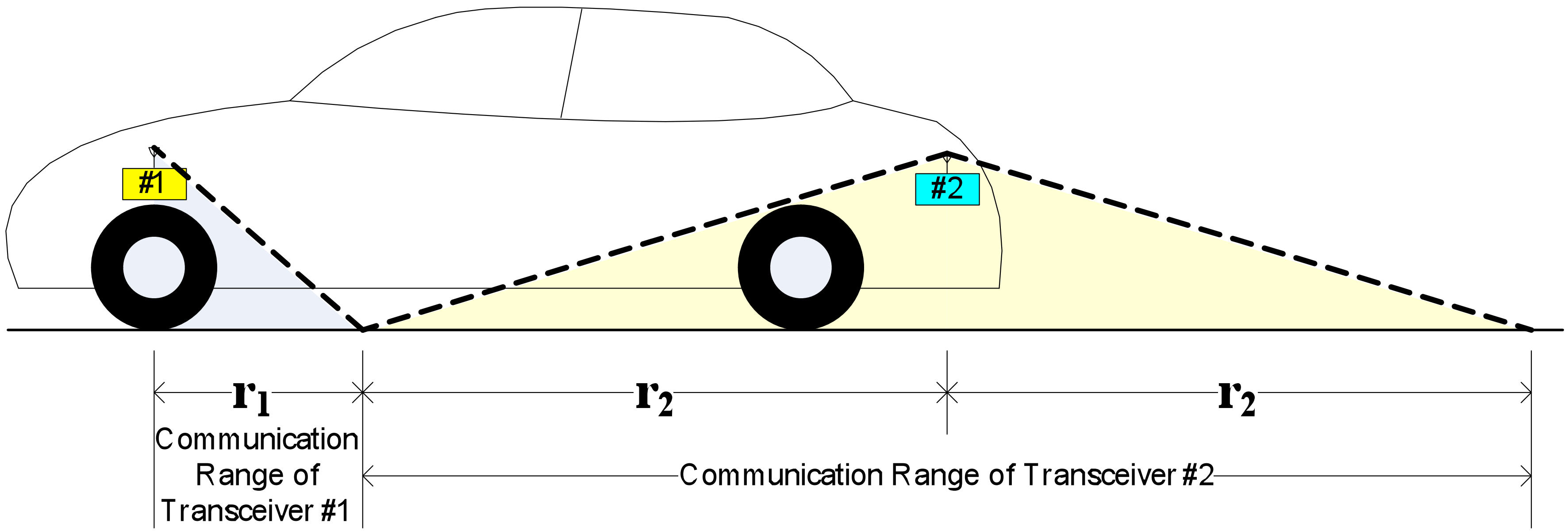
3. The wireless communication system

Vehicle-to-Vehicle communication

- this communication mode is vulnerable to security and privacy attacks and is supposed to be used very rarely
- NOTICE may use this communication in case of emergency situation with slow traffic
- a vehicle which has already stored incident information from a given belt can forward this information to other vehicles running ahead directly through wireless link

3. The wireless communication wystem

The communication process

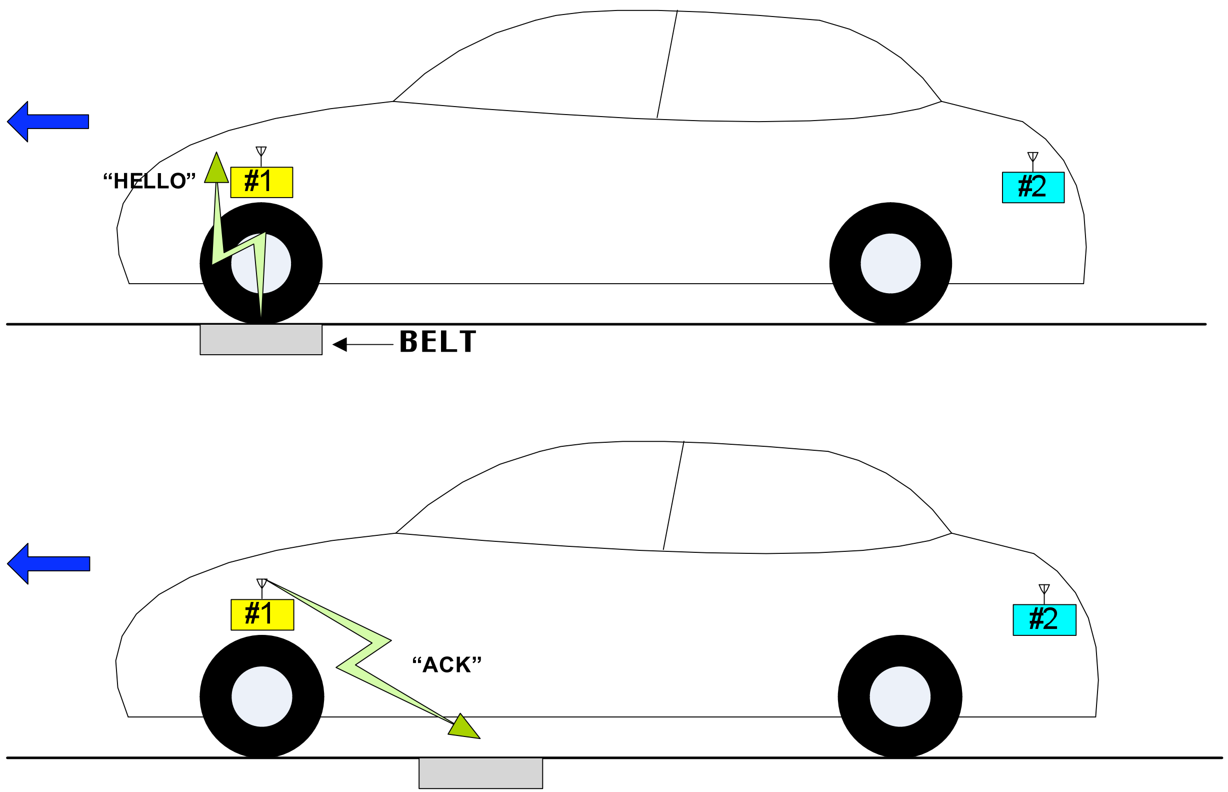


3. The wireless communication system

- Handshaking
  - “HELLO” and “ACK” dialogue
  - must be finished before leaving the radio range #1, otherwise the process fails
  - vehicle identity and encryption are not required but belt identity is needed
- Data exchange
  - traffic information is exchanged between the belt and the vehicle
  - information secured by encryption
  - must be completed before leaving the radio range #2

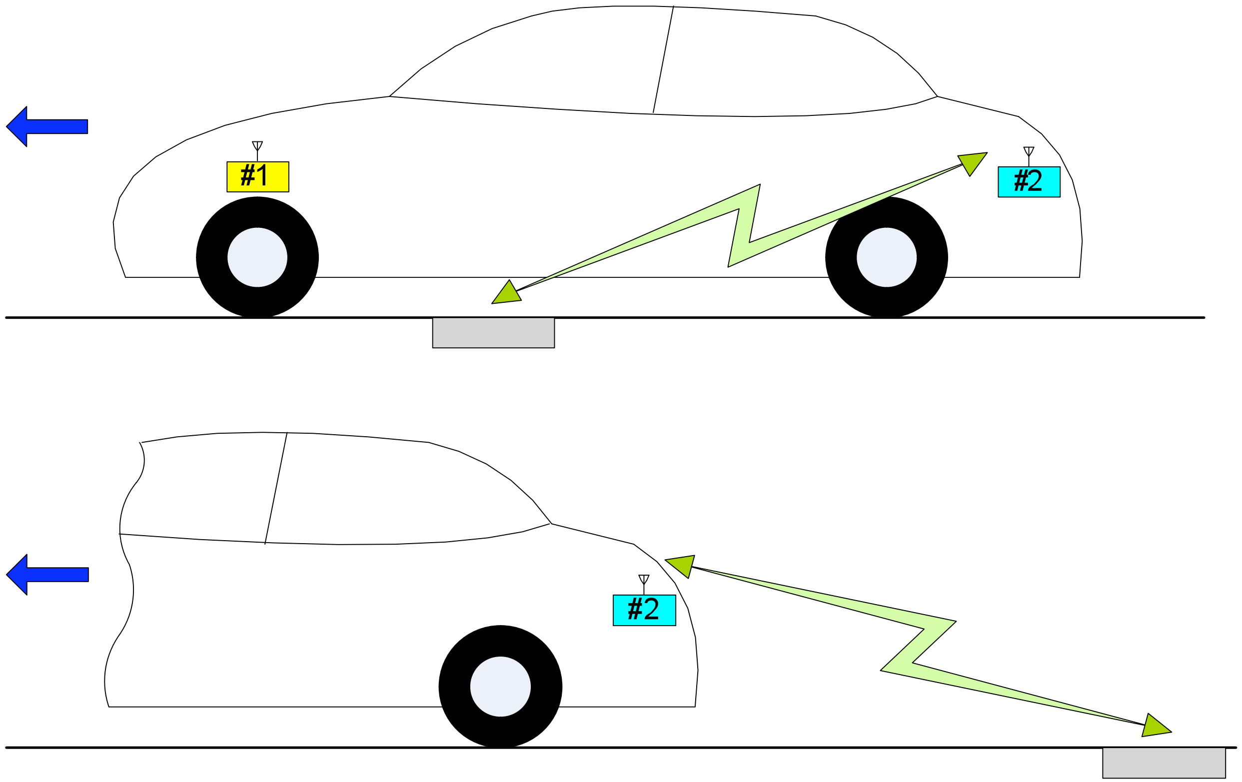
3. The wireless communication system

Handshaking



3. The wireless communication system

Information exchange

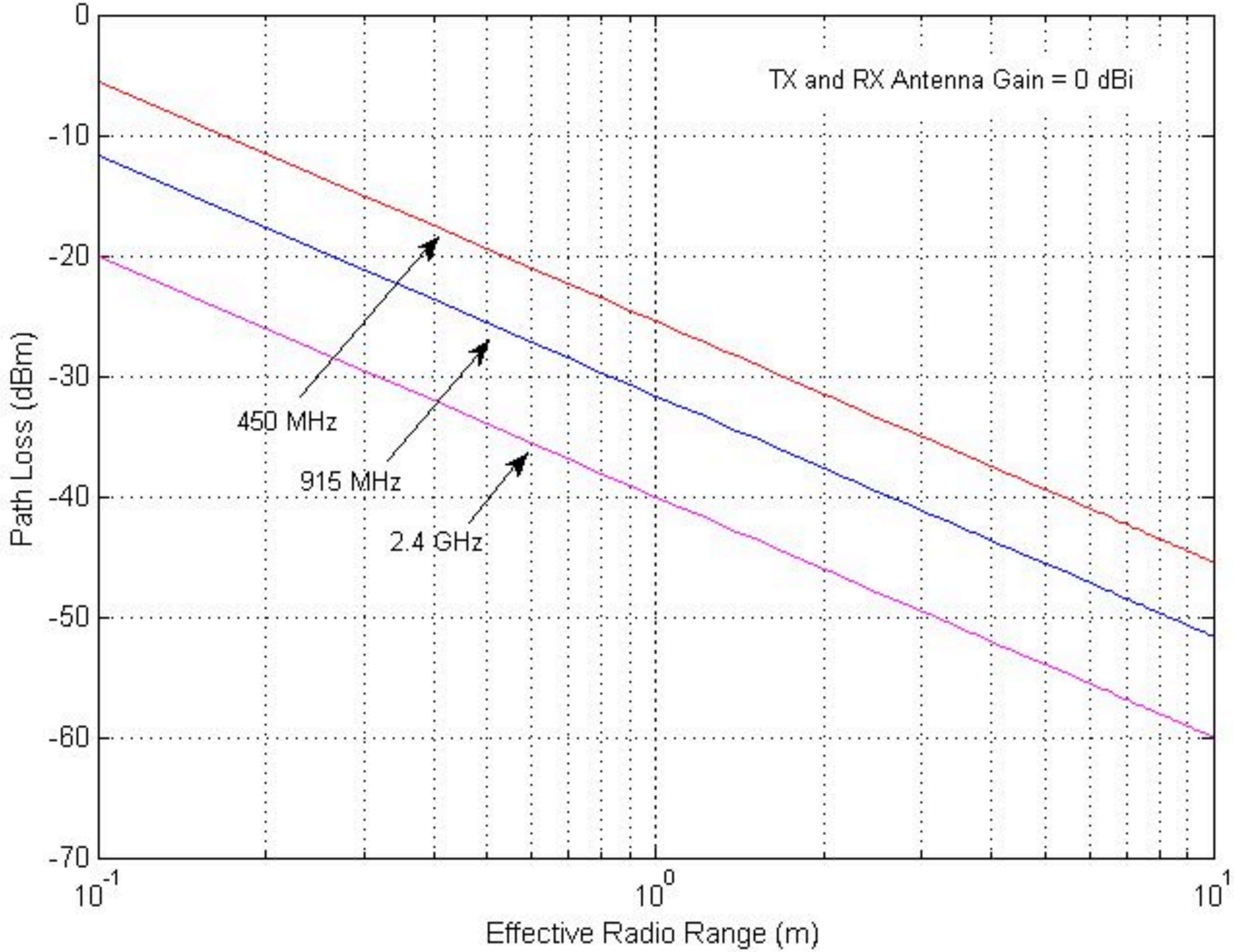


3. The wireless communication system

- Radio range available for communication
  - NOTICE employs short-range wireless communication
    - participating cars have limited time to complete vehicle-to-belt communication
    - the effective communication range must be taken into consideration
  - the applicable radio propagation model is free-space propagation
    - communicating over line-of-sight

3 The wireless communication system

$$P_R = P_T.G_T.G_R.\left(\frac{\lambda}{4\pi r}\right)^2 \qquad [W]$$



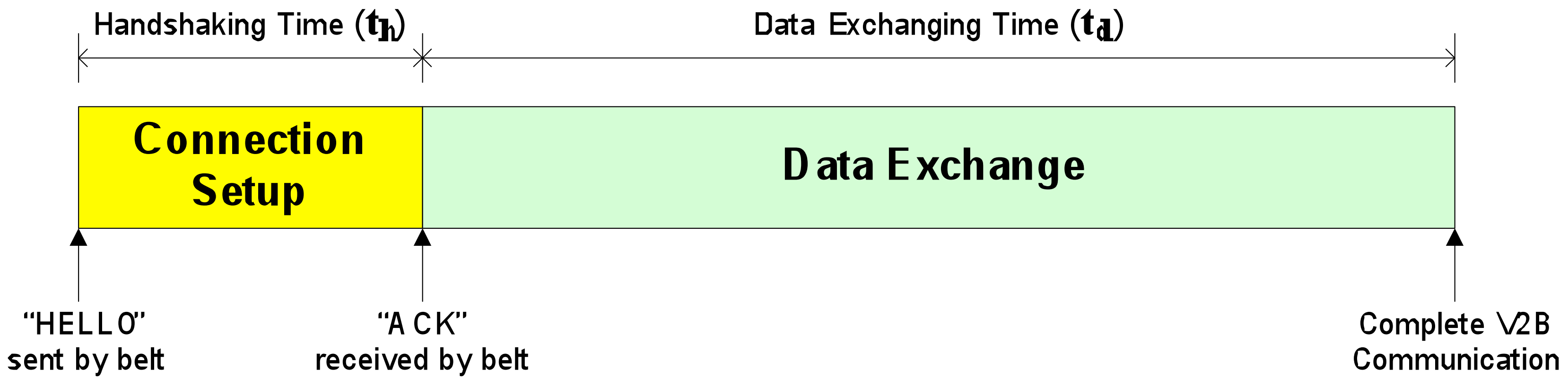
3. The wireless communication system

- several short-range wireless systems have emerged such as RFID, Bluetooth, ZigBee, and Wi-Fi operating at various frequencies such as 450MHz, 902-920 MHz, 2.4 GHz, and ISM band

- NOTICE provides two communication ranges:
  - r_1 for handshaking and r_2 for information exchange
  - although every car is provided the same radio ranges, they take different time to establish communication successfully because they travel at different speed

3. The wireless communication system

- We also consider radio ranges available for vehicle-to-belt communication in terms of available time



3. The wireless communication system

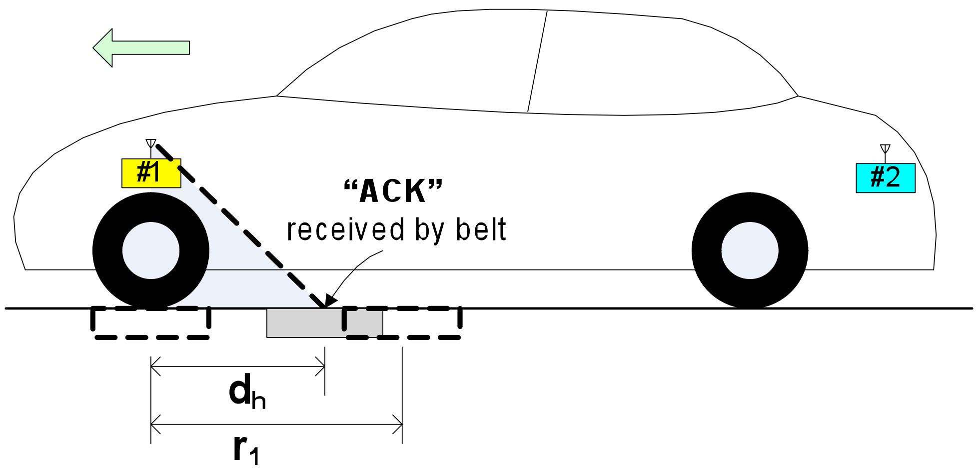
Successful handshaking

$$\boxed{d_h \leq r_1}$$

$$t_h = \frac{d_h}{v}$$

$$t_{ah} = \frac{r_1}{v}$$

$$\boxed{t_h \leq t_{ah}}$$



t_{ah} denotes the maximum time available for the vehicle and the belt to establish handshaking successfully at a given speed

3. The wireless communication system

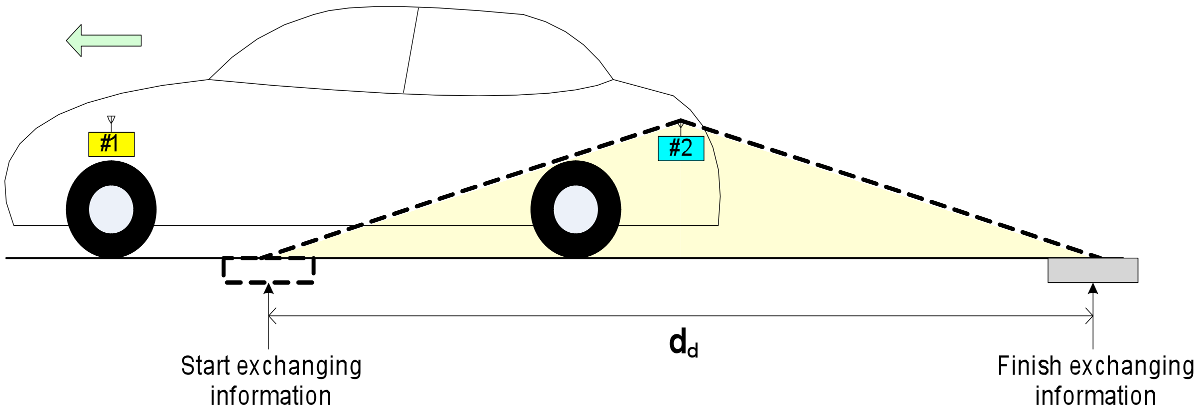
Successful data exchange

$$d_d \leq 2.r_2$$

$$t_{ad} = \frac{2.r_2}{v}$$

$$t_d = \frac{d_d}{v}$$

$$t_d \leq t_{ad}$$



t_{ad} denotes the maximum time available for the vehicle and the belt to establish data exchange successfully at a given speed

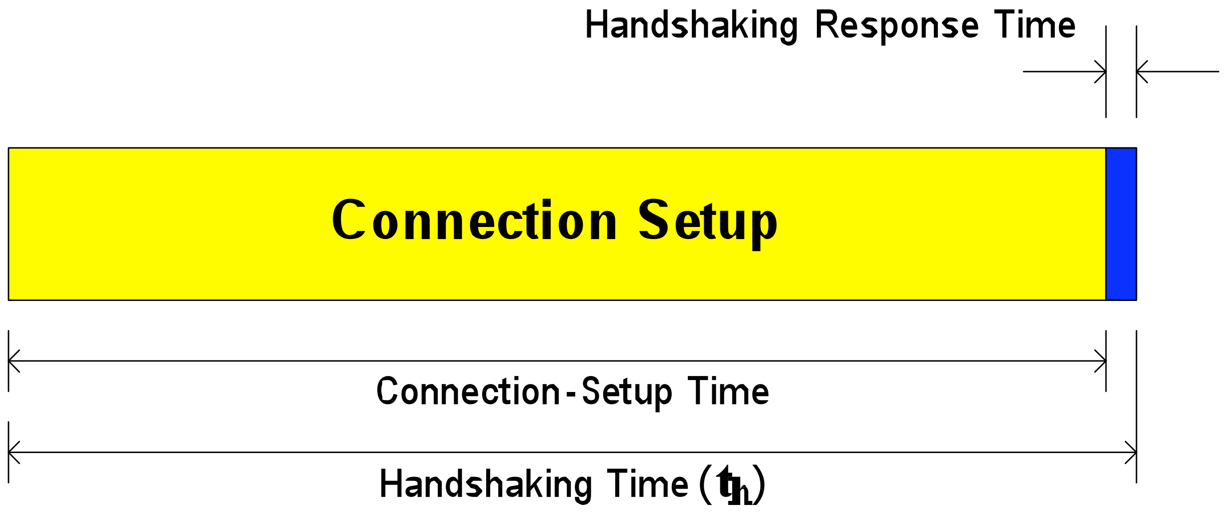
3. The wireless communication system

- t_h, t_{ah}, t_d, and t_{ad} depend on the vehicle speed
- in order to have successful vehicle-to-belt communication, transceivers #1 and #2 must have $t_h \leq t_{ah}$ and $t_d \leq t_{ad}$, respectively
- in practice, vehicles on the highway travel at different speed around the posted speed limit
- the timing intervals t_{ah} and t_{ad} can be very short if vehicle speed is very high and as a consequence, the vehicle may not handshake successfully

4. Analyzing vehicle-to-belt communication

Handshaking stage

- handshaking time (t_h) combines time for connection setup and time for handshaking responses (“HELLO” and “ACK”)



4. Analyzing vehicle-to-belt communication

  - connection setup time is a property of a wireless system and tends to have a specific value, for example, ZigBee requires about 30 ms and Bluetooth needs more than one second
  - handshaking time is assumed equal to connection setup time because handshaking response time is very small → data rate can be ignored for handshaking analysis
- The probability of successful handshaking (P_{sh}) is the likelihood that the vehicle and the belt handshake successfully before the vehicle moves out of the radio range of transceiver #1

4. Analyzing vehicle-to-belt communication

$$P_{sh} = Prob\{t_h \leq t_{ah}\}$$

- t_{ah} is the available handshaking time for a given speed
- T_{ah} is the average available handshaking time of all participating vehicles

$$k_1 = \frac{r_1}{T_{ah}} \quad \rightarrow \quad r_1 = k_1.T_{ah}$$

$$t_{ah} = \frac{r_1}{v}$$

$$t_{ah} = \frac{k_1.T_{ah}}{v}$$

4. Analyzing vehicle-to-belt communication

$$P_{sh} = Prob\left\{t_h \leq \frac{k_1.T_{ah}}{v}\right\}$$

$$= Prob\left\{v \leq \frac{k_1.T_{ah}}{t_h}\right\}$$

$$= F_v\left(\frac{k_1.T_{ah}}{t_h}\right)$$

- vehicle speed (*v)* is assumed to be a Gaussian random variable with N(μ, σ^2)

$$F_v(v) = \int_{-\infty}^{v} \frac{1}{\sigma\sqrt{2\pi}}\, e^{\frac{-(x-\mu)^2}{2\sigma^2}}\, dx$$

4. Analyzing vehicle-to-belt communication

$$P_{sh} = \int_{-\infty}^{\frac{k_1.T_{ah}}{t_h}} \frac{1}{\sigma\sqrt{2\pi}}\, e^{\frac{-(x-\mu)^2}{2\sigma^2}}\, dx$$

$$Q(y) \triangleq \frac{1}{\sqrt{2\pi}} \int_{y}^{\infty} e^{\frac{-z^2}{2}}\, dz$$

Let $z = \frac{x-\mu}{\sigma}$

$$P_{sh} = 1 - \int_{\frac{\frac{k_1.T_{ah}}{t_h}-\mu}{\sigma}}^{\infty} \frac{1}{\sqrt{2\pi}}\, e^{\frac{-z^2}{2}}\, dz$$

$$= 1 - Q\left(\frac{\frac{k_1.T_{ah}}{t_h} - \mu}{\sigma}\right)$$

4. Analyzing vehicle-to-belt communication

$$erf(x) \triangleq \frac{2}{\sqrt{\pi}} \int_0^x e^{-y^2}\, dy \qquad\qquad Q(x) = \frac{1}{2} - \frac{1}{2} erf\left(\frac{x}{\sqrt{2}}\right)$$

$$P_{sh} = \frac{1}{2} + \frac{1}{2} erf\left(\frac{\frac{k_1.T_{ah}}{t_h} - \mu}{\sigma\sqrt{2}}\right)$$

- P_{sh} depends on connection setup time (t_h), average speed (u), available handshaking time (T_{ah}), and radio range (r_1)

4. Analyzing vehicle-to-belt communication

Data exchange

- The probability of successful data exchange (P_{sd}) is the probability that total amount of data required to be exchanged between the vehicle and the belt can be transmitted successfully within the available data exchange time
  - the amount of data in data exchange stage is much larger than that of handshaking stage
  - the amount of data is not constant due to variability of incident/traffic information
  - NOTICE provides longer communication range and available time for data exchange (~6 times)

4. Analyzing vehicle-to-belt communication

- thus, data exchange time (t_d) cannot be estimated as a constant like handshaking time (t_h)
- to determine t_d, data rate and amount of data must be involved
- considering upper bound of $t_d \leq t_{ad}$ → $t_d = t_{ad}$ as the worse case
- t_{ad} is the available data exchange time for a given speed
- T_{ad} is the average available data exchange time of all participating vehicles

$$k_2 = \frac{2.r_2}{T_{ad}}$$

4. Analyzing vehicle-to-belt communication

$$t_{ad} = \frac{2.r_2}{v} = \frac{k_2.T_{ad}}{v}$$

$$\boxed{P_{sd} = 1 - Prob\{d < I\}}$$

$$d = D.t_d = D.t_{ad} \boxed{= D.\frac{k_2.T_{ad}}{v}}$$

$$P_{sd} = 1 - Prob\left\{\frac{D.k_2.T_{ad}}{v} < I\right\}$$

$$= 1 - Prob\left\{v > \frac{D.k_2.T_{ad}}{I}\right\}$$

$$= F_v\left(\frac{D.k_2.T_{ad}}{I}\right)$$

4. Analyzing vehicle-to-belt communication

$$P_{sd} = \int_{-\infty}^{\frac{D.k_2.T_{ad}}{I}} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} dx$$

$$P_{sd} = 1 - Q\left(\frac{\frac{D.k_2.T_{ad}}{I} - \mu}{\sigma}\right)$$

$$\boxed{P_{sd} = \frac{1}{2} + \frac{1}{2} erf\left(\frac{\frac{D.k_2.T_{ad}}{I} - \mu}{\sigma\sqrt{2}}\right)}$$

- P_{sd} depends on data rate (D), amount of data (I), average speed (u), available data exchange time (T_{ad}), and radio range (r_2)

5. Simulation results

Simulation setup

- a single belt embedded in one lane of the highway
- number of vehicles passing the belt is Poisson distributed with given mean equals traffic flow and observation time of 60 minutes
- sparse traffic (600 vehicles/hour/lane) and moderate traffic (1200 vehicles/hour/lane)
- vehicle speeds are independent and identically distributed and have a Gaussian probability density function

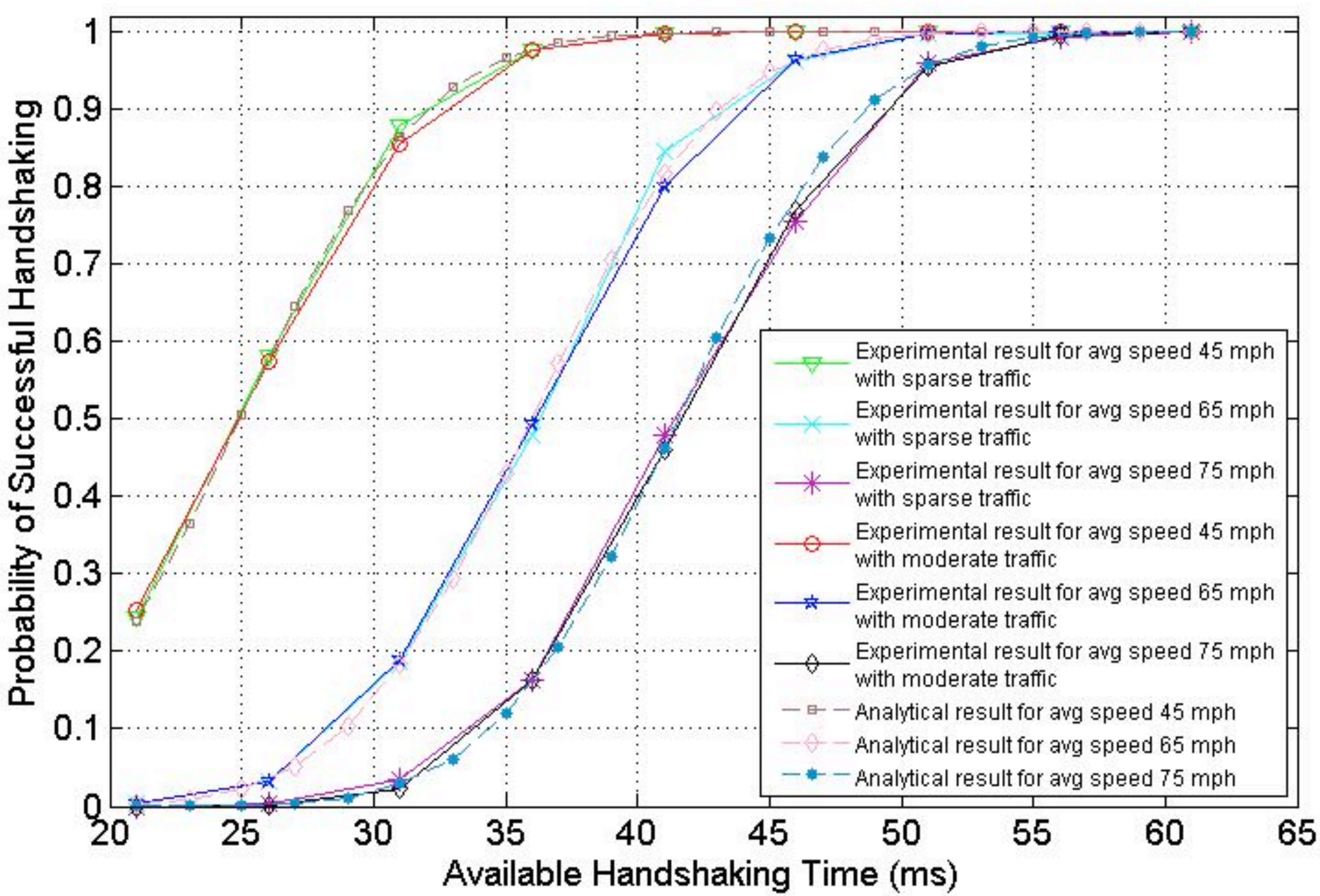
5. Simulation results

- Organization of experiments

Experiment	Probability	T_{ah}, r_1	t_h	T_{ad}, r_2	D	I	μ
1	P_{sh}	varied	fixed	-	-	-	fixed
2	P_{sh}	fixed	varied	-	-	-	fixed
3	P_{sh}	fixed	fixed	-	-	-	varied
4	P_{sd}	-	-	fixed	fixed	fixed	varied
5	P_{sd}	-	-	varied	fixed	fixed	fixed

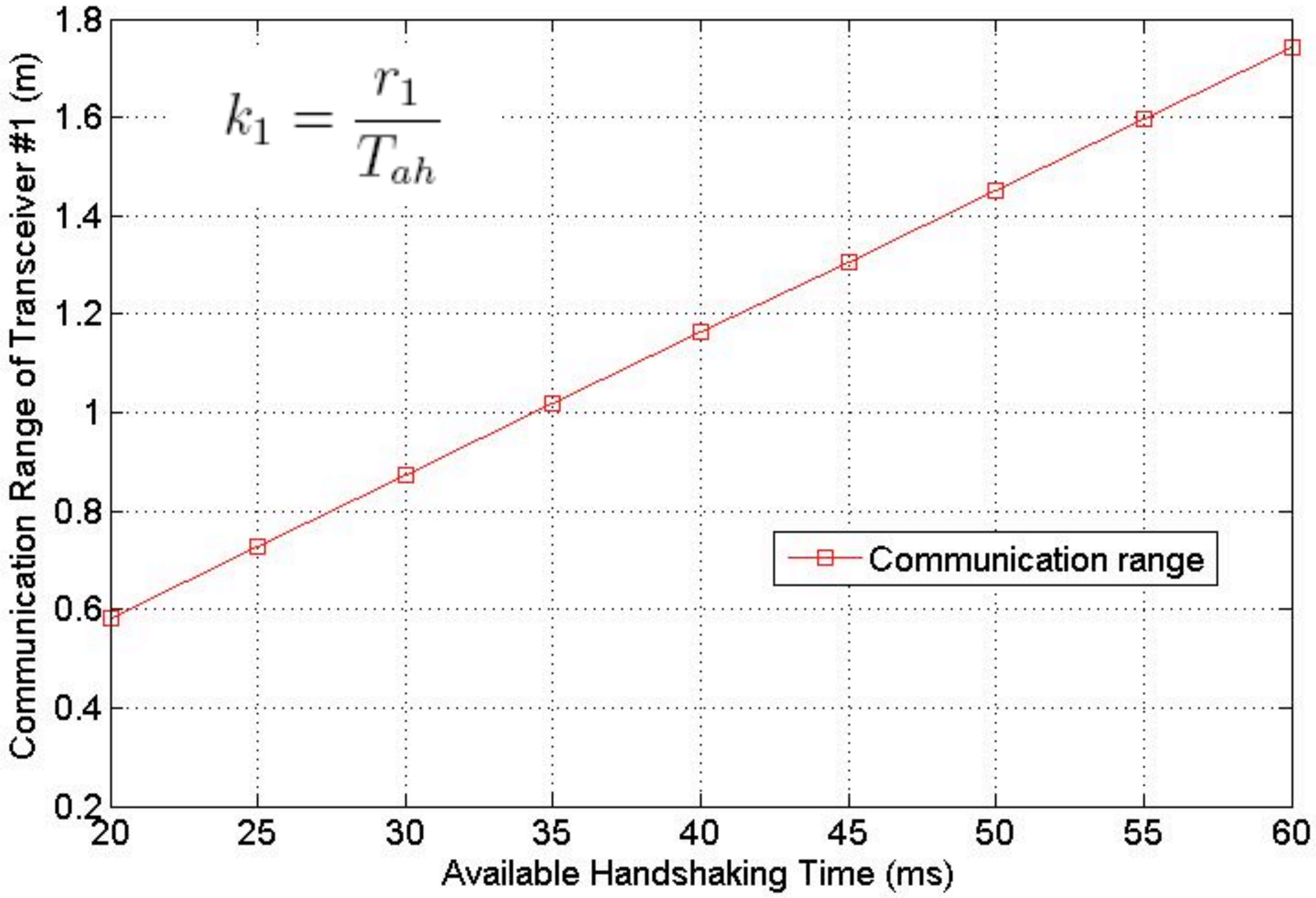
Connection Setup and Handshaking

1) t_h = 36 ms, μ = 45, 65, 75 mph, T_{ah} is varied.



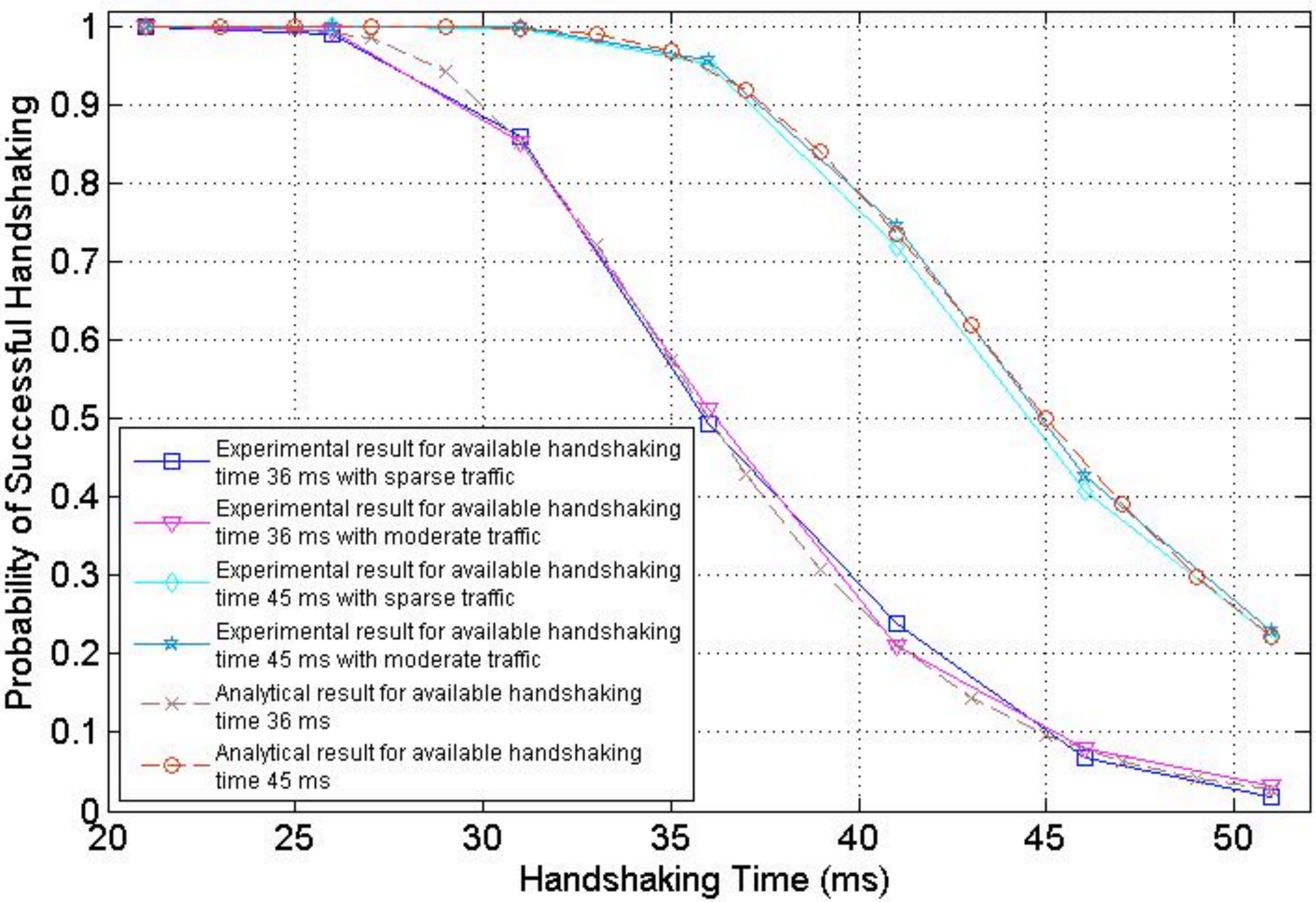
Connection Setup and Handshaking

- communication range of transceiver #1



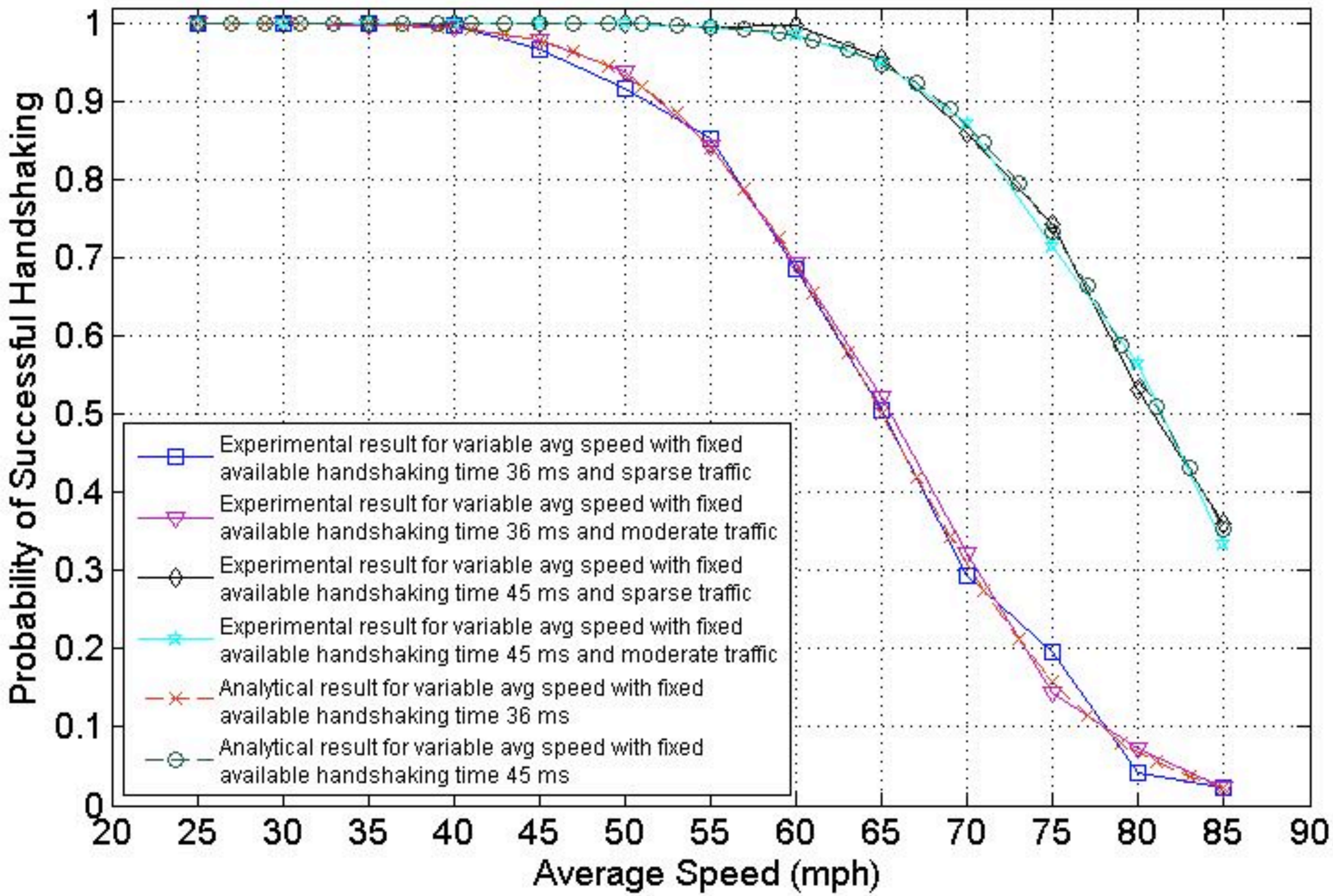
Connection Setup and Handshaking

2) t_h is varied, μ = 65 mph, T_{ah} = 36, 45 ms



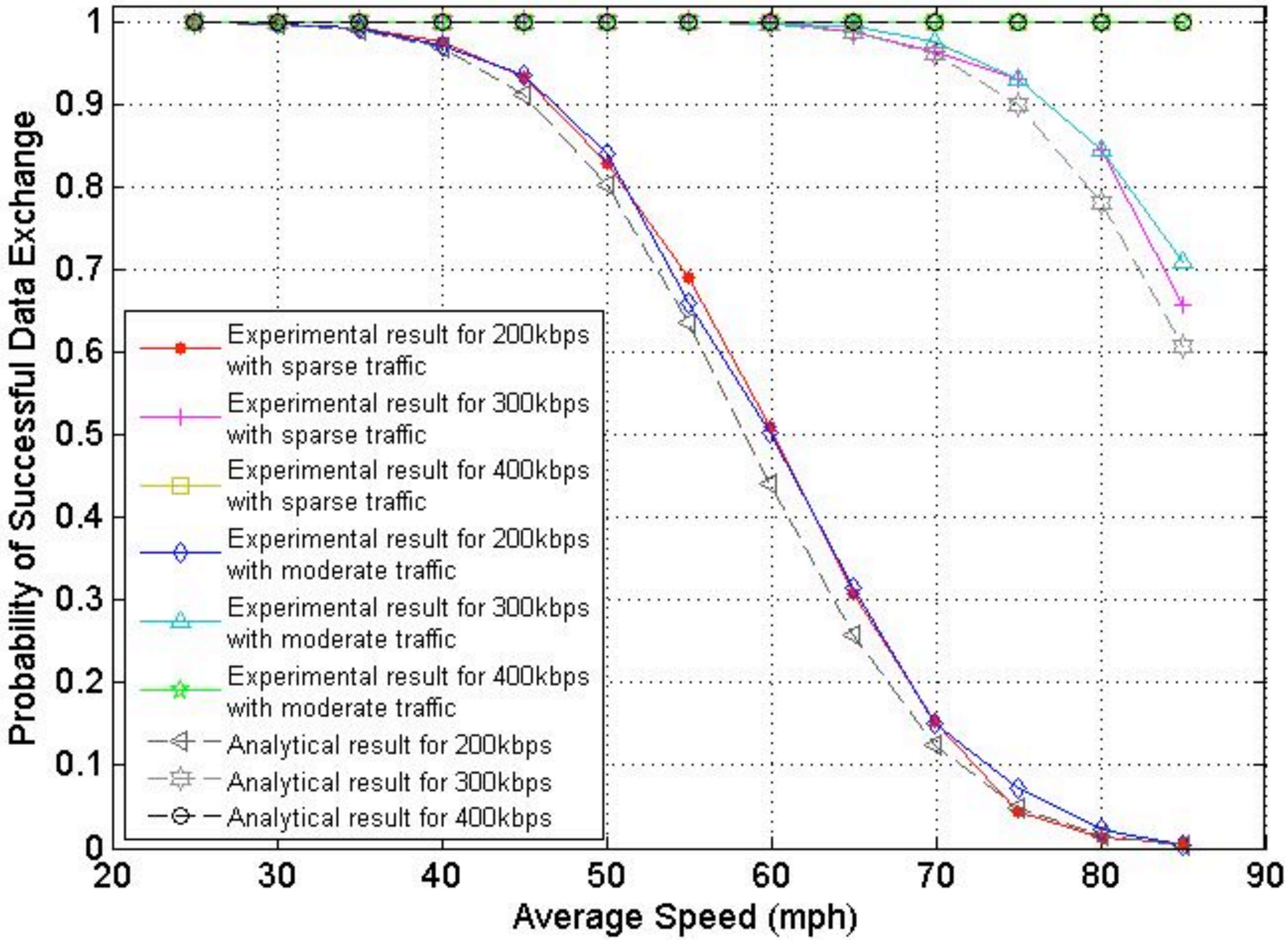
Connection Setup and Handshaking

3) t_h = 36 ms, μ is varied, T_{ah} = 36, 45 ms



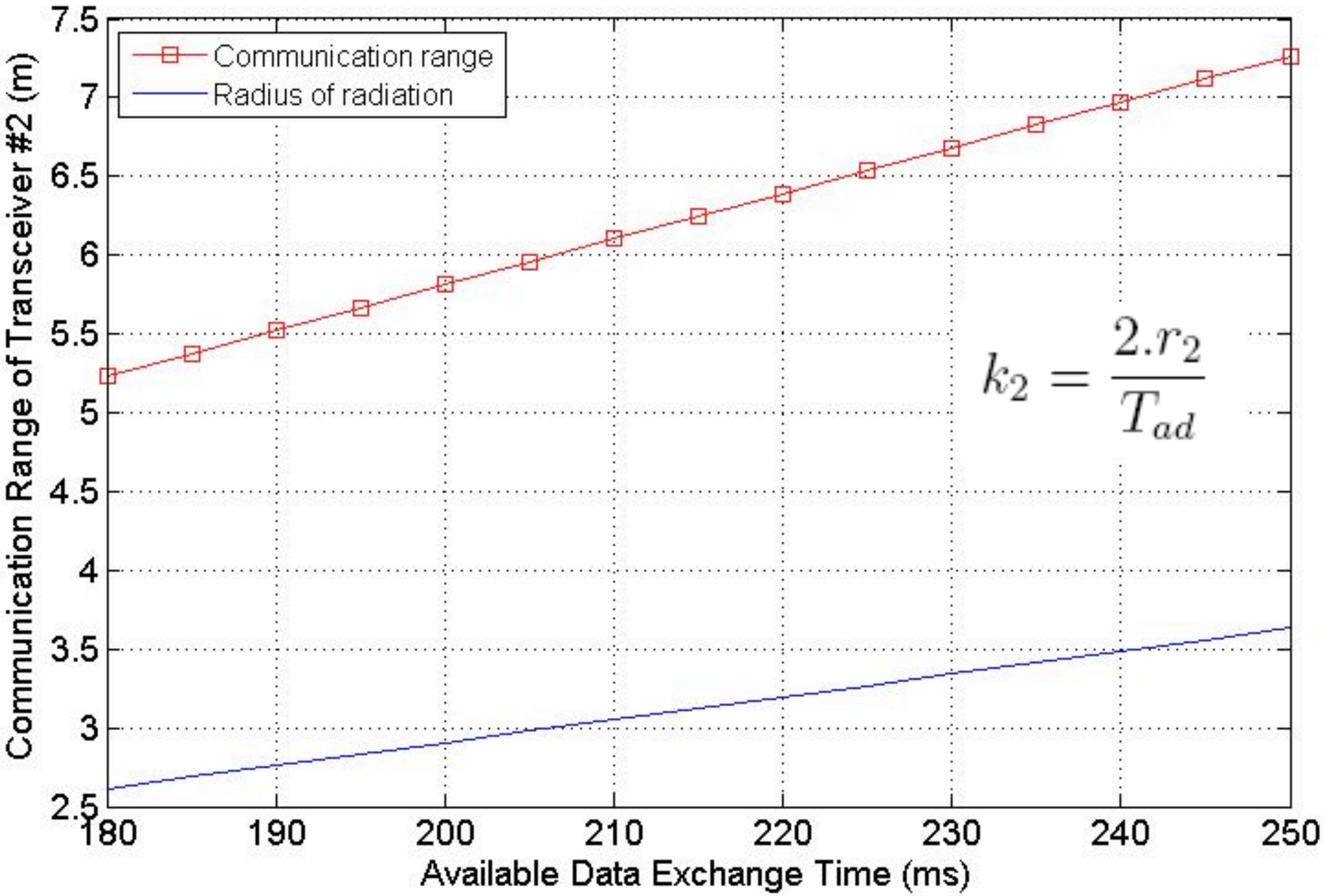
Data exchange

4) D=200,300,400 kbps, μ is varied, T_{ad}=216 ms, l=6kbytes



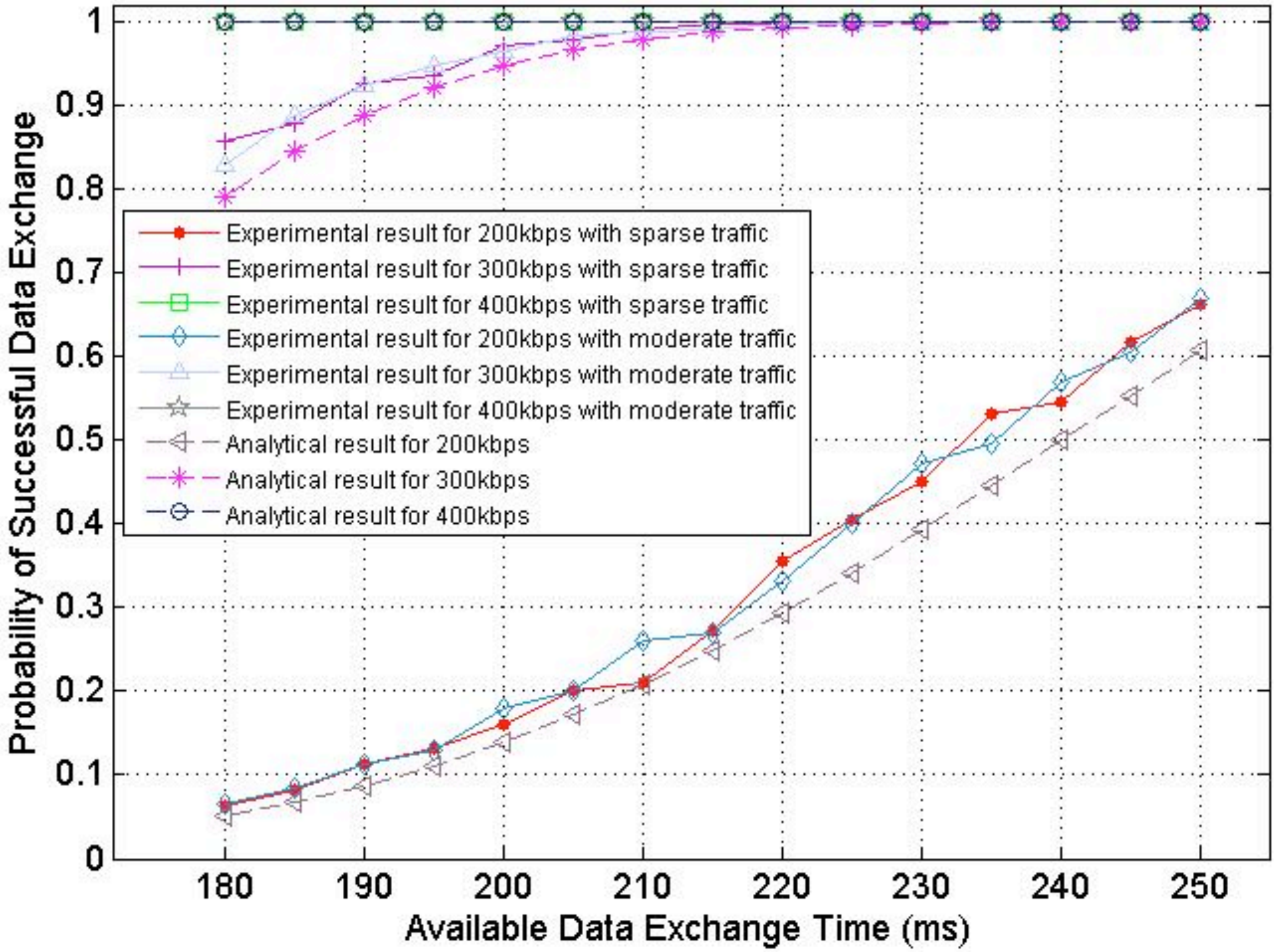
Data exchange

- communication range of transceiver #2



Data exchange

5) d=200,300,400 kbps, μ=65 mph, T_{ad} is varied, l=6kbytes



6. Concluding remarks

- Vehicle-to-belt communication is the primary communication mode
- Successful vehicle-to-belt communication must handle both successful handshaking and data exchange
  - successful handshaking is influenced by connection setup time, available handshaking time, communication range #1, and vehicle speed
  - successful data exchange is influenced by data rate, amount of data, available data exchange time, communication range #2, and vehicle speed

6. Concluding remarks

- The probabilities of successful handshaking and data exchange are independent of the type of traffic
  - successful vehicle-to-belt communication is not impacted by the flow of vehicles passing over the belt
- Our experimental results agree with the theoretical derivations
- Handshaking and data exchange are independent events. Thus, the probability of successful vehicle-to-belt communication is the product of their corresponding probabilities
  - assuming a probability of successful vehicle-to-belt communication of 80% → an incident would be detected within one minute

6. Concluding remarks

- The time available for vehicle-to-belt communication can be increased by using transceivers that require shorter connection setup time
  - however, the communication range is constrained by the vehicle length and the security awareness
- Our findings:
  - the transceiver should require ≤ 40 ms for connection setup time and should have data rate of ≥ 300 kbps
  - radio ranges of transceiver #1 and #2 are about 1.3 m and between 5.5-6 m, respectively
  - ZigBee came across as the best candidate

References

M. Abuelela, S. Olariu, and M. Weigle, NOTICE: An architecture for notification of traffic incidents, *Proc 65th IEEE Vehicular Technology Conference - VTC'08 Spring*, Singapore, May 2008

D. Rawat, D. Treeumnuk, D. Popescu, M. Abuelela, and S. Olariu, Challenges and perspectives in the implementation of NOTICE architecture for vehicular communications, *Proc 2nd International Workshop on Vehicular Networks*, USA, 2008

M. Abuelela, S. Olariu, M. Cetin and D. Rawat, Enhancing automatic incident detection using vehicular communications, *Proc 70th IEEE Vehicular Technology Conference - VTC'09 Fall*, 2008

M. Abuelela and S. Olariu, A probabilistic technique for detecting permanent and temporary incidents in VANET, *Proc. 6th Workshop on Intelligent Transportation* (WIT 2009), Hamburg, Germany, April 2009