Control of Aggregated Power Level of Safety Messages in VANET

C265 Spring ’09 Class Project

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Outline

- VANET and Safety Enhancement
- Why Aggregated Power Level Should be Studied?
- PDE Model of Aggregated Power Level with Uniform Tx Rate and Power
- Summary

Vehicular Ad-Hoc Network

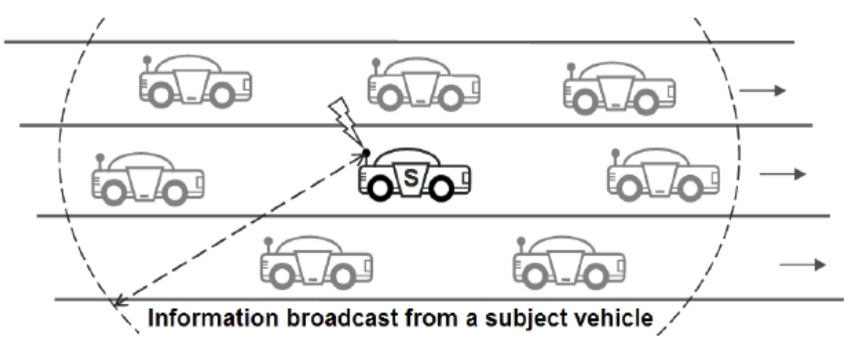
- VANET: Wireless transceivers put on cars for real-time information exchange
  - No need for Access Point. Cars can talk to cars in ad hoc mode
  - First priority (of U.S. government, NHTSA) is to enhance highway safety
- VSCC report (vehicle safety communication consortium, 2005) suggests two kinds of safety messages
  - Status update messages
  - Event-driven (emergency) messages

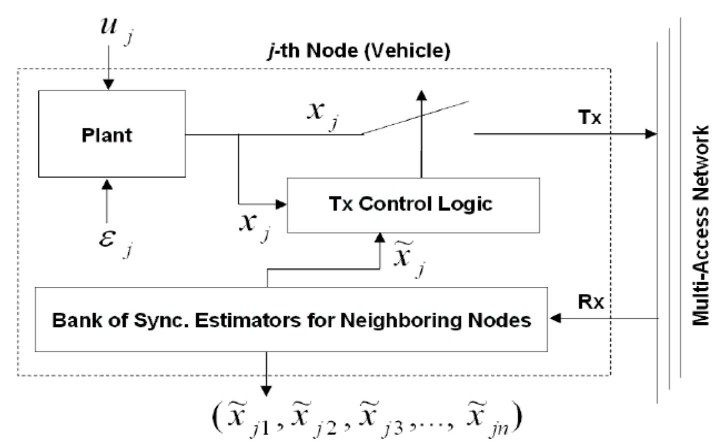
Conceptually, VANET looks like this...

(from http://www.intellidriveusa.org)

Status Update Messages

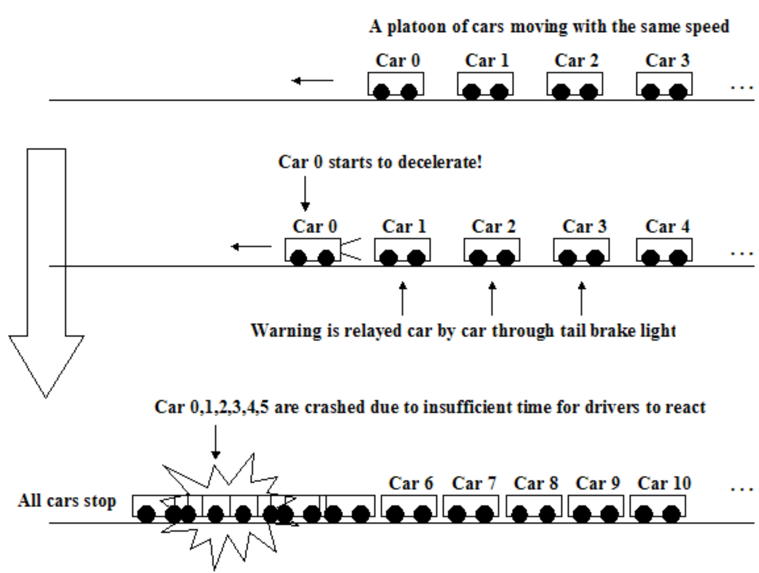
- Subject vehicle broadcasts its own state information, e.g. position, speed, heading, to neighboring vehicles
  - Based on received information, other vehicles estimate the position, speed, heading of that subject vehicle
- Every car tries to track other cars and get a "digital map" of all neighboring vehicles' movement
  - Various safety applications rely on this kind of "proximity awareness" (e.g. 150m radius)
- VSCC report suggests 100ms beacon interval

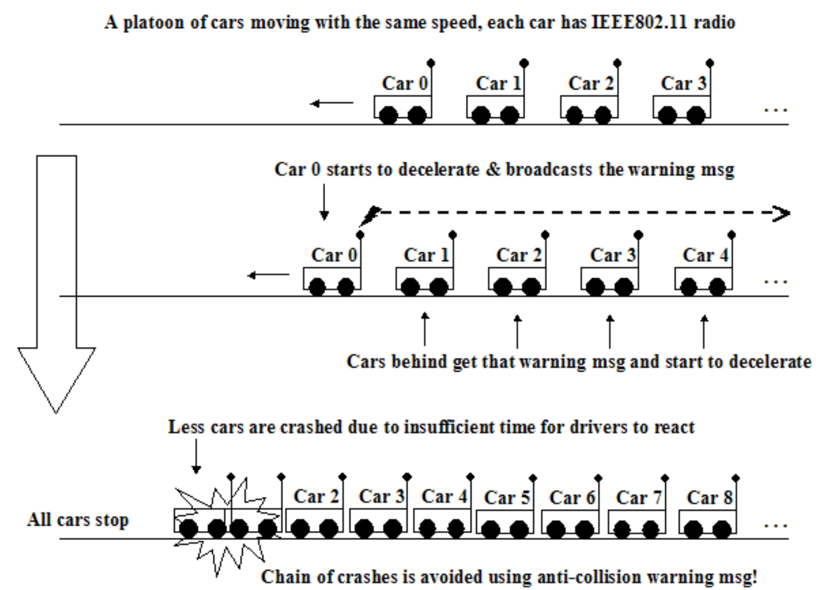




Event-Driven Messages

- When a car senses a hazardous situation, it initiates a warning messages to other cars
  - E.g. a crashed car can warn other cars of this condition and potential change of traffic
  - Wireless messages travel faster than shock wave
- Not as frequent as status update messages.
  - But it is time-critical! It needs higher successful reception probability





Why Tx Power/Rate of Status Update Messages Should Be Studied?

- The delivery of time-critical event-driven messages needs to be protected from interference of frequent status update messages
  - It uses maximum Tx power… but is that enough?
- The aggregated power level from all status update messages becomes interference (noise) to an event-driven message
  - E.g. talking in a party (with loud background music)
  - For event-driven messages, its SNR (signal-to-noise ratio) decides BER (bit error rate) and PER (packet error rate) given messages size
- VSCC suggests fixed Tx rate (100ms interval) and fixed Tx power (100mW=20dBm) for all cars
  - Is this a good idea? Let's use PDE to analyze the aggregated power level from status update messages

Stochastic Channel Model

Given a pair of sender-receiver, if the sender transmits with power τ, given the distance d (separation of sender-receiver), the received power ω can be calculated by:

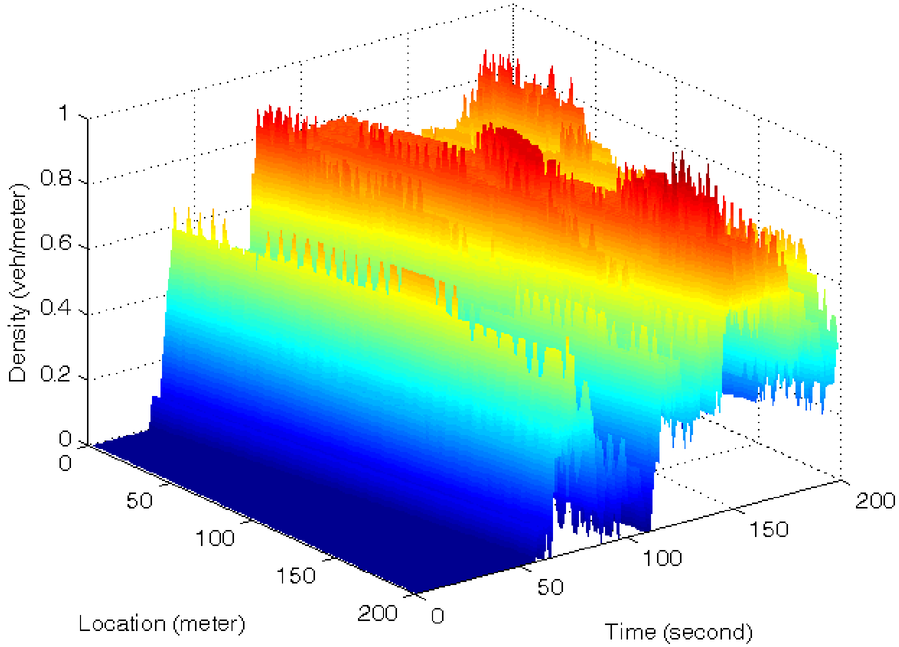
$$\omega(\tau, d) = \phi \times \frac{\tau}{d^{\gamma}} \times z_1 \times z_2 \quad (1)$$

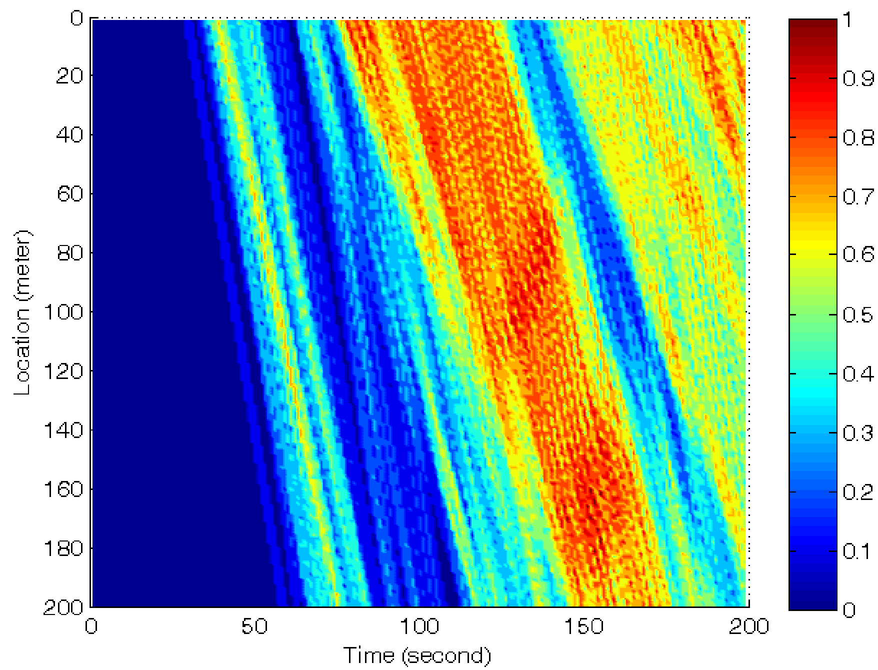
where ϕ is a constant, $\gamma \geq 2$ represents path loss exponent of the DSRC channel, z_1 and z_2 represent shadowing and multi-path effect respectively.

- Path loss exponent (energy dissipation)
  - Usually 2~3 for outdoor environment
- Shadowing effect (large scale fading)
  - Usually modeled as log-normal distribution
- Multi-path effect (small scale fading)
  - Usually modeled as Rayleigh, Rician, or Nakagami-k distribution
- Each sender-receiver pair can be calculated **independently**
  - Aggregated power is the superposition of all transmissions

Vehicular Density of Simulated 4-lane Straight Highway

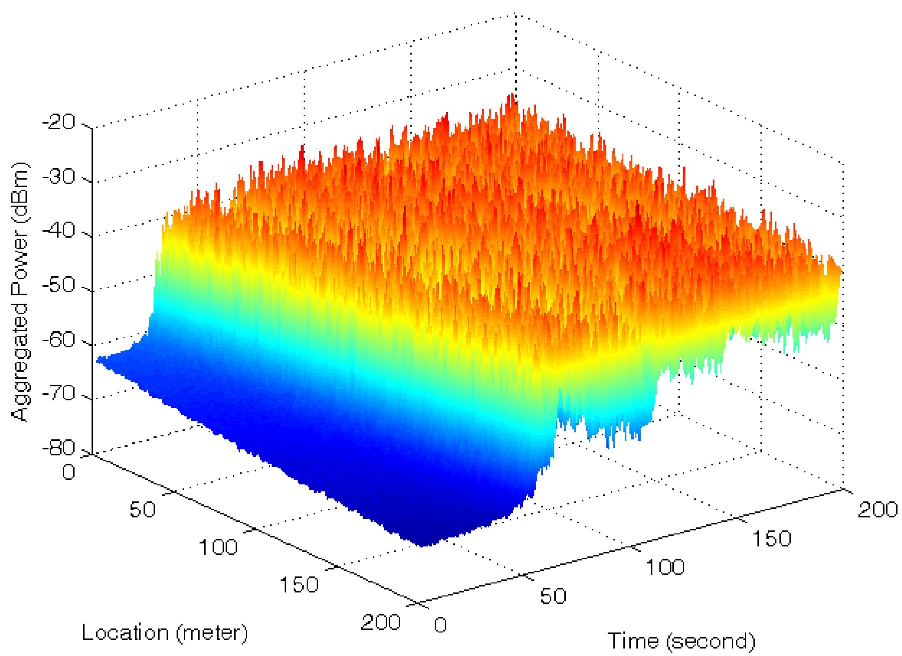
- Microscopic traffic simulator (PATH SHIFT)
  - http://path.berkeley.edu/smart-ahs/index.html
- Density is calculated by moving average (10m window) over a 200m segment of highway
  - An empty highway is gradually populated by vehicles

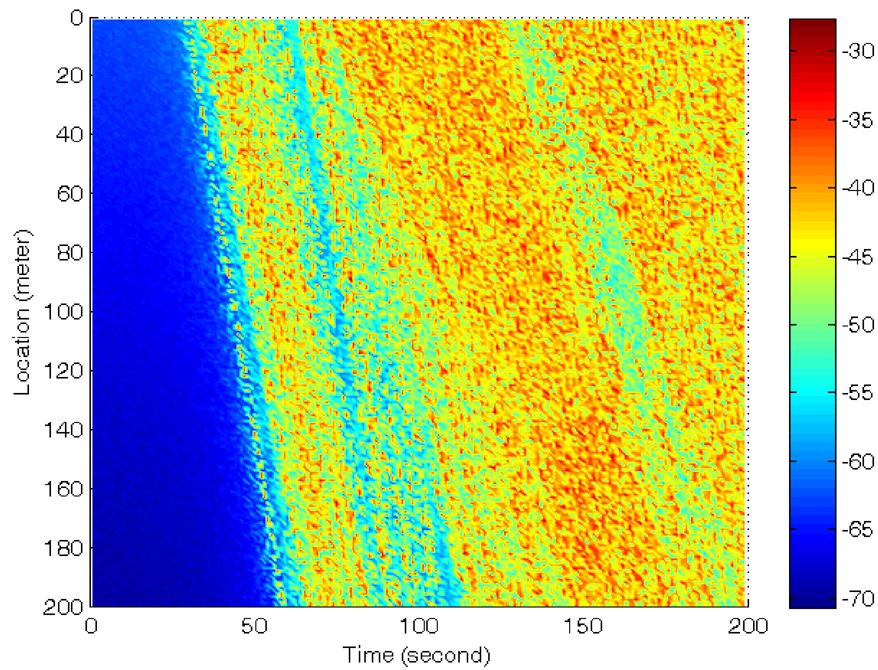




Aggregated Power Level (dBm) in DSRC for Simulated Highway

- Shown plot is just one sample path (realization)
  - Note that, dBm is a log-scale measure of power (mW)
- Aggregated power level has correlation with vehicular traffic since each vehicle uses uniform Tx rate/power





PDE Model of Aggregated Power Level with Uniform Rate/Power

With Greenshield's flux function, $\boxed{\text{LWR PDE}}$ (15) can be written as,

$$\boxed{\frac{\partial \rho(x,t)}{\partial t} + v_f(1 - \frac{2\rho(x,t)}{\rho^*})\frac{\partial \rho(x,t)}{\partial x} = 0 \qquad (17)}$$

where ρ^* is the jam density and v_f is the free-flow velocity.

For notational convenience in following derivation, let $\nu(x,y,t) = \frac{\rho(x+y,t)+\rho(x-y,t)}{y^\gamma}$ and $\boxed{\overline{c}(x,t) = \frac{E[c(x,t)]}{\Phi\lambda\tau}}$, then (8) can be rewritten as

$$\overline{c}(x,t) = \int_0^\infty \nu(x,y,t)dy. \qquad (20)$$

By taking partial derivative of $\nu(x,y,t)$ w.r.t. x and t,

$$\frac{\partial \nu(x,y,t)}{\partial t} = \frac{1}{y^\gamma}(\frac{\partial \rho(x+y,t)}{\partial t} + \frac{\partial \rho(x-y,t)}{\partial t}) \qquad (21)$$

and

$$\frac{\partial \nu(x,y,t)}{\partial x} = \frac{1}{y^\gamma}(\frac{\partial \rho(x+y,t)}{\partial x} + \frac{\partial \rho(x-y,t)}{\partial x}). \qquad (22)$$

Combining (21) and (22), we get a version for $\nu(x,y,t)$ similar to (17),

$$\frac{\partial \nu(x,y,t)}{\partial t} + v_f(1 - \frac{2\rho(x,t)}{\rho^*})\frac{\partial \nu(x,y,t)}{\partial x} = 0 \qquad (23)$$

where ρ^* is the jam density and v_f is the free-flow velocity as in (10). Now take partial derivative of $\overline{c}(x,t)$ w.r.t. t and x,

$$\frac{\partial \overline{c}(x,t)}{\partial t} = \int_0^\infty \frac{\partial \nu(x,y,t)}{\partial t}dy \qquad (24)$$

and

$$\frac{\partial \overline{c}(x,t)}{\partial x} = \int_0^\infty \frac{\partial \nu(x,y,t)}{\partial x}dy. \qquad (25)$$

Therefore, from integrating the form of (23), we get

$$\boxed{\frac{\partial \overline{c}(x,t)}{\partial t} + v_f(1 - \frac{2\rho(x,t)}{\rho^*})\frac{\partial \overline{c}(x,t)}{\partial x} = 0. \qquad (26)}$$

Let $\mu(x,y,t) = \frac{\rho(x+y,t)^2+\rho(x-y,t)^2}{y^{2\gamma}}$ and $\boxed{\widetilde{c}(x,t) = \frac{V[c(x,t)]}{\Psi\lambda^2\tau^2}}$, we get

$$\boxed{\frac{\partial \widetilde{c}(x,t)}{\partial t} + v_f(1 - \frac{2\rho(x,t)}{\rho^*})\frac{\partial \widetilde{c}(x,t)}{\partial x} = 0. \qquad (27)}$$

Solution to PDE Using Characteristics

Based on the technique of characteristics, we get

$$\boxed{\frac{dx}{dt} = v_f(1 - \frac{2\rho(x,t)}{\rho^*}), \qquad (29)}$$

and thus the mean and variance of aggregated power,

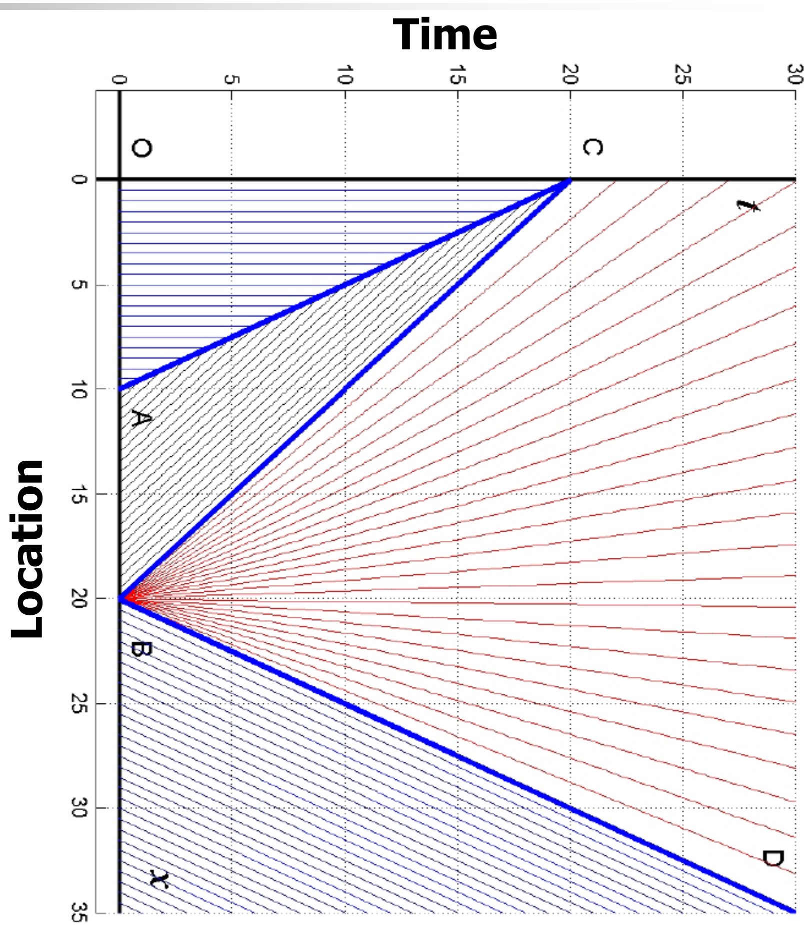
$$E[c(x,t)] = E[c(x - v_f(1 - \frac{2\rho(x,t)}{\rho^*})(t-t_0), t_0)], \qquad (30)$$

and

$$V[c(x,t)] = V[c(x - v_f(1 - \frac{2\rho(x,t)}{\rho^*})(t-t_0), t_0)]. \qquad (31)$$

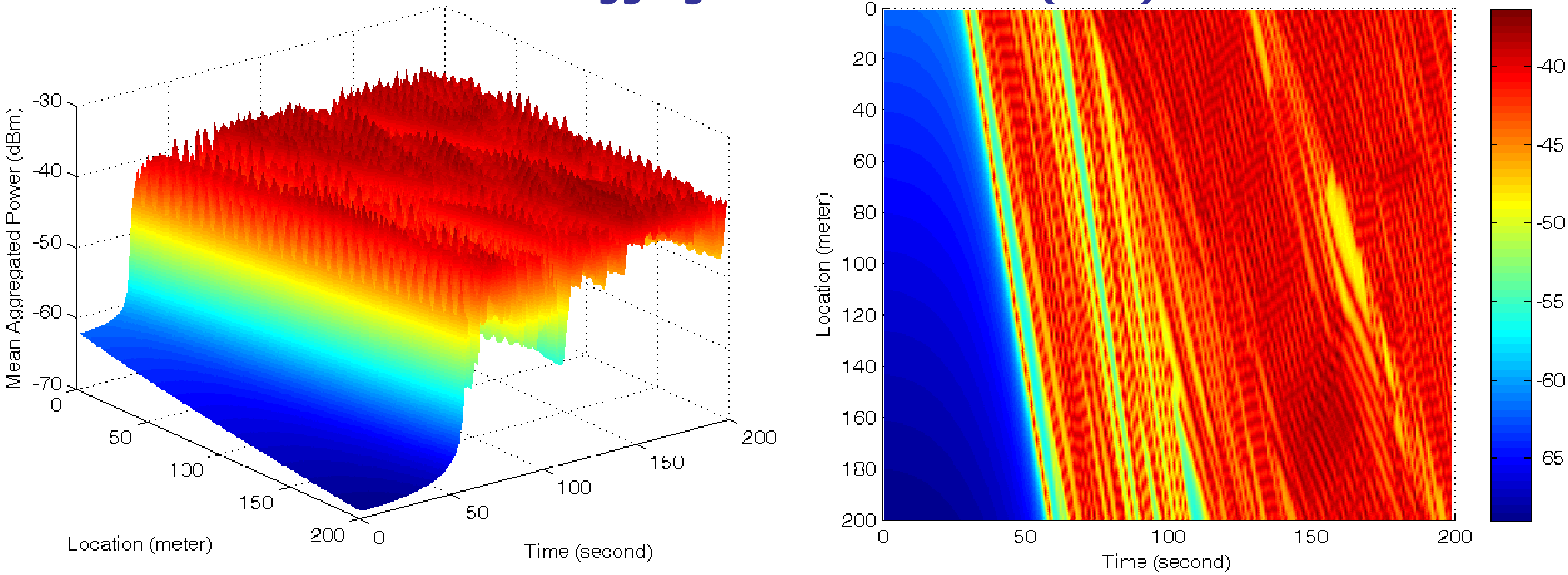
In fact, the same can be shown for all cumulants of $c(x,t)$ (mean and variance are the first two cumulants). Therefore, the distribution of $c(x,t)$, $f(c(x,t)) \in [0,1]$, can be expressed similarly,

$$\boxed{f(c(x,t)) =^d f(c(x - v_f(1 - \frac{2\rho(x,t)}{\rho^*})(t-t_0), t_0)). \qquad (32)}$$

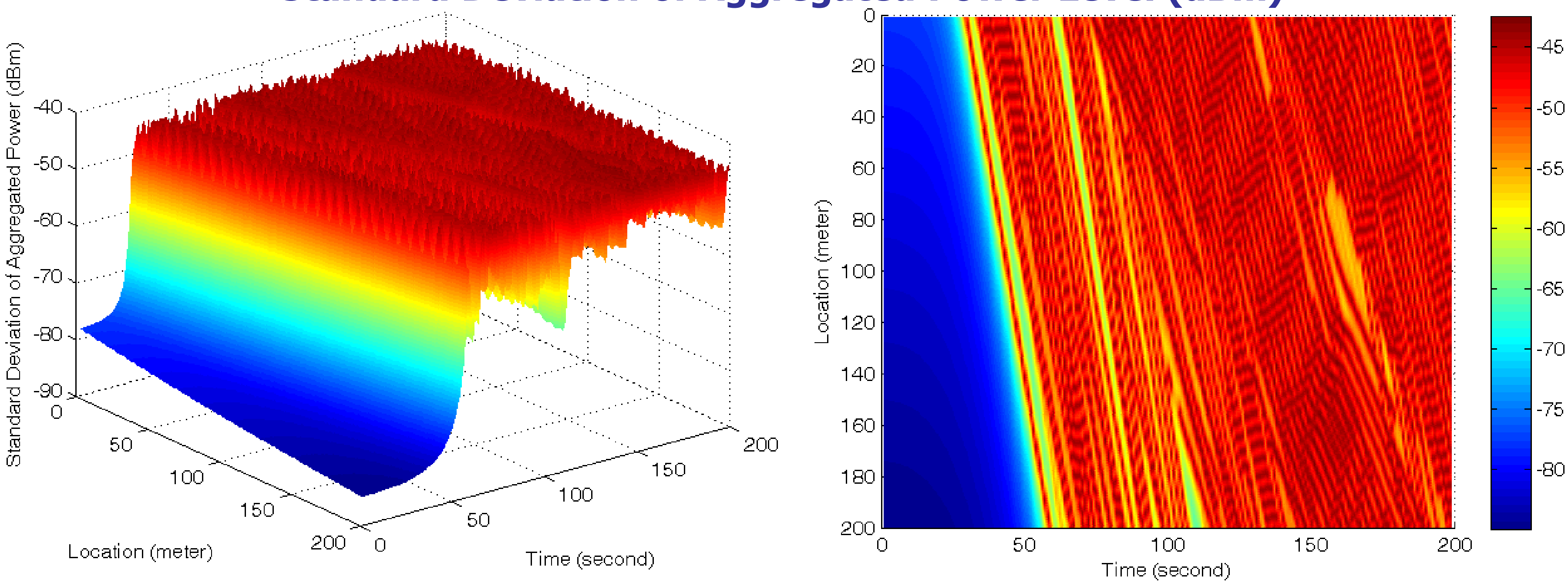


Just an illustration from pp.63 of class note

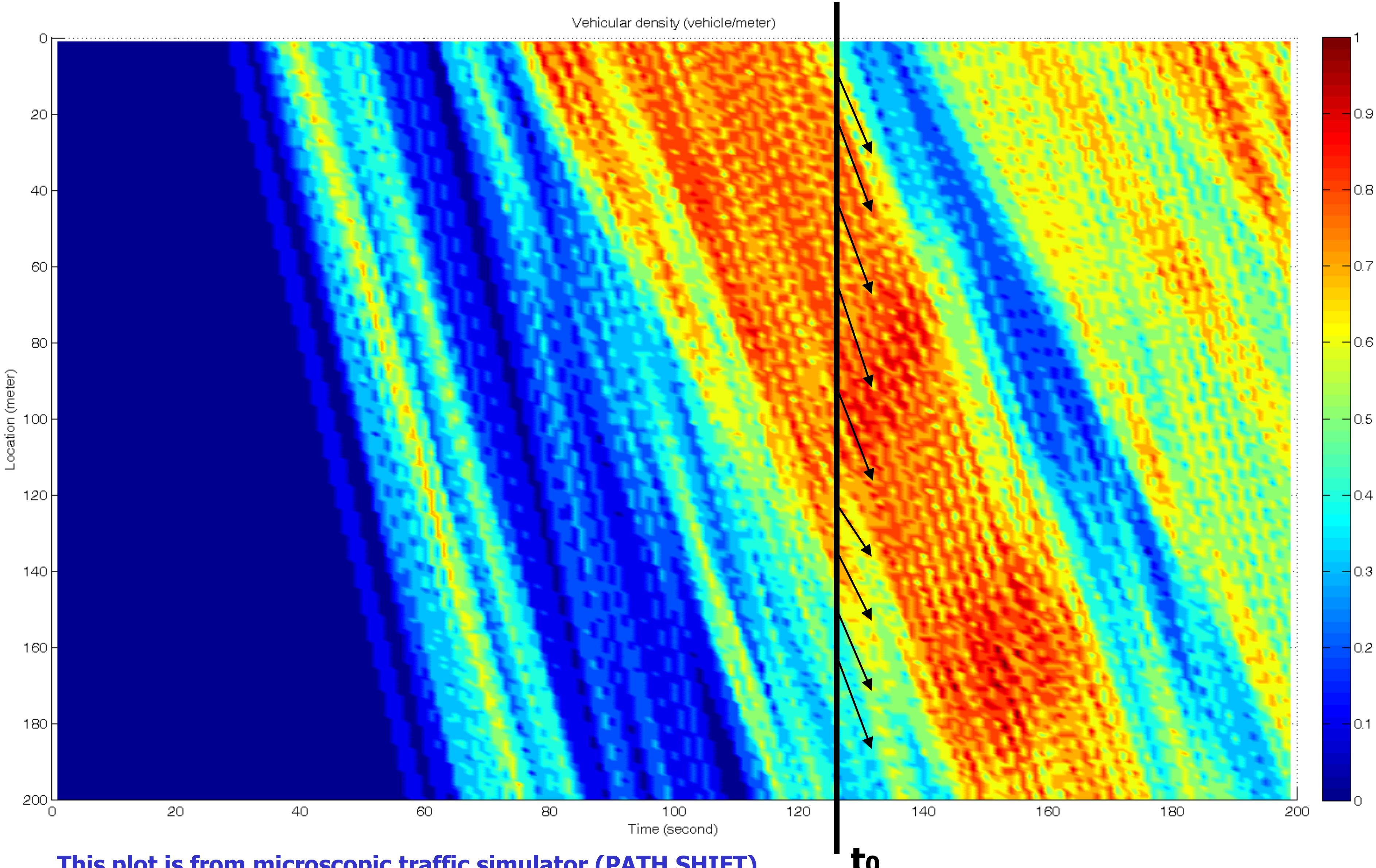
Mean of Aggregated Power Level (dBm)



Standard Deviation of Aggregated Power Level (dBm)

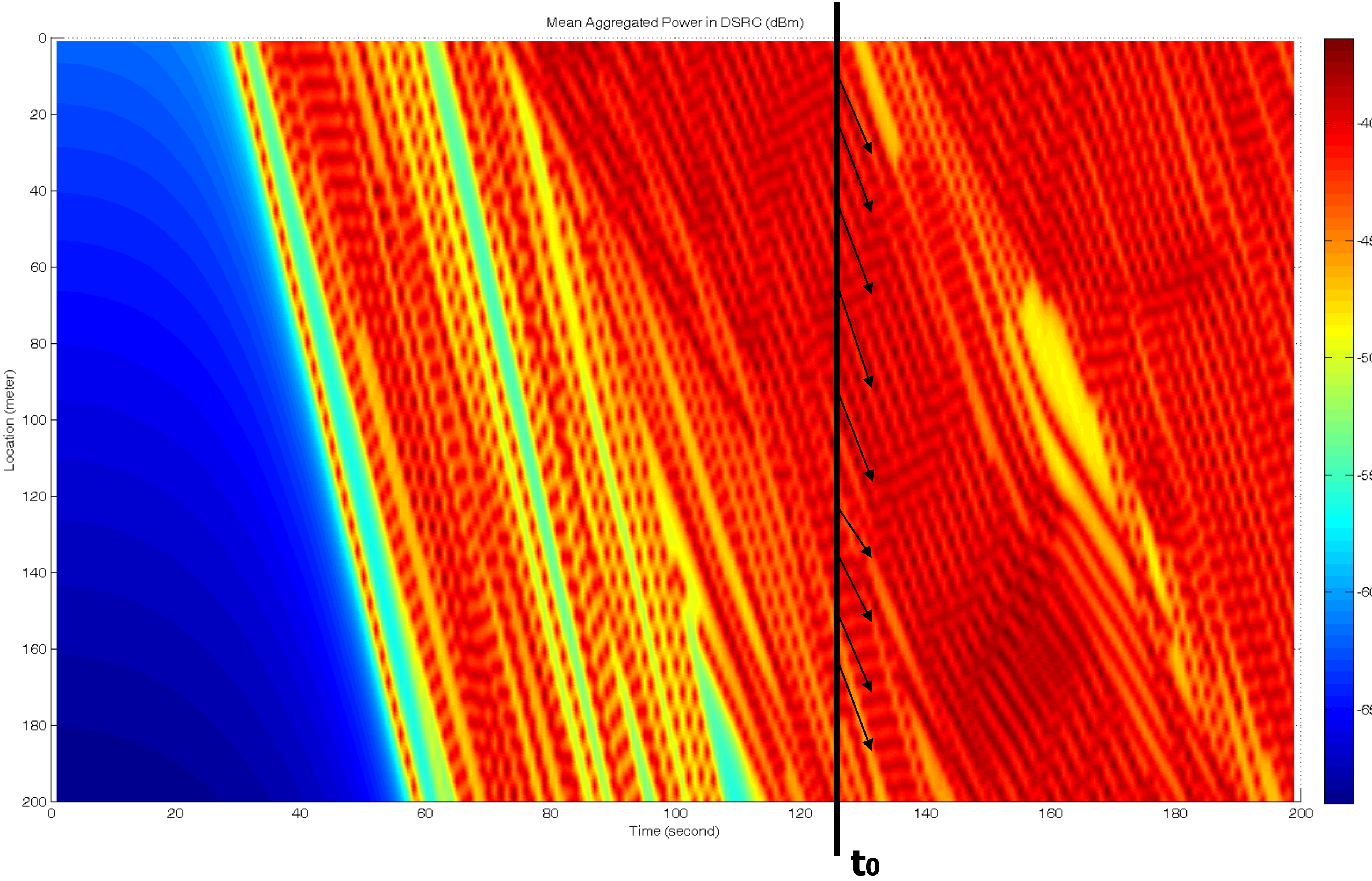


Do You See the Characteristics of Vehicular Density?

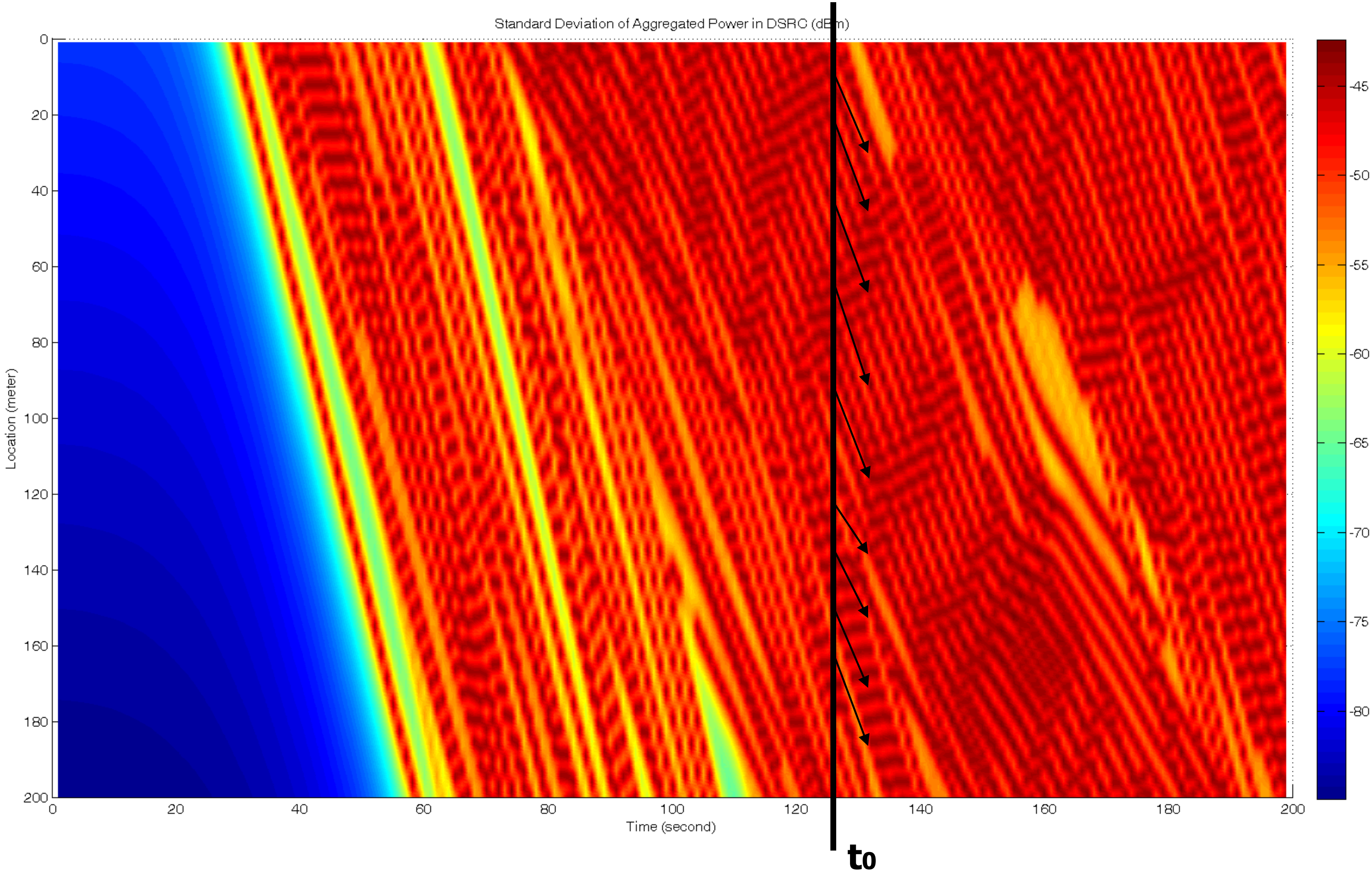


This plot is from microscopic traffic simulator (PATH SHIFT)

Characteristics of Mean Aggregated Power



Characteristics of Std. Dev. of Aggregated Power



Summary

- Introduce VANET and safety enhancement
  - Rate/power control problem of status update messages in DSRC
- Model aggregated power level in DSRC using PDE
  - Show characteristics in vehicular density and (mean, variance) of aggregated power in DSRC
  - Show ideas to control aggregated power efficiently
- Work to be done before end of semester:
  - Simulate SNR, BER, PER of event-driven messages
  - Finalize the report

Thanks for your patience! Q&A

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