BMAS 2010
September 23-24, 2010
San Jose, California, USA

Baseband Fading Channel Simulator For Inter-Vehicle Communication Using SystemC-AMS

Abdelbasset Massouri
Laurent Clavier
Andreas Kaiser
IEMN

Antoine Lévêque
Michel Vasilivski
Marie-Minerve Loërat
LIP6-UPMC

Supported by: ANR ***WASABI*** Project
Wireless system ***A***nd ***S***ystemC-AMS : ***B***asic ***I***nfrastructure
Partners: STMicroelectronics Grenoble, Magillem Design Services

MOTIVATION

BMAS 2010
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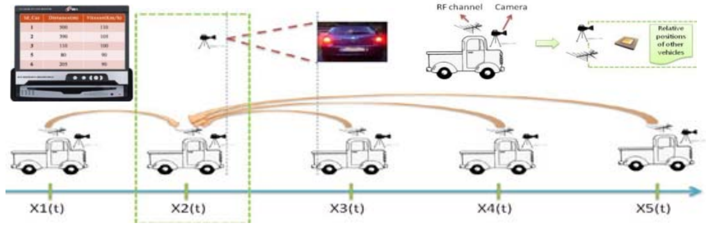
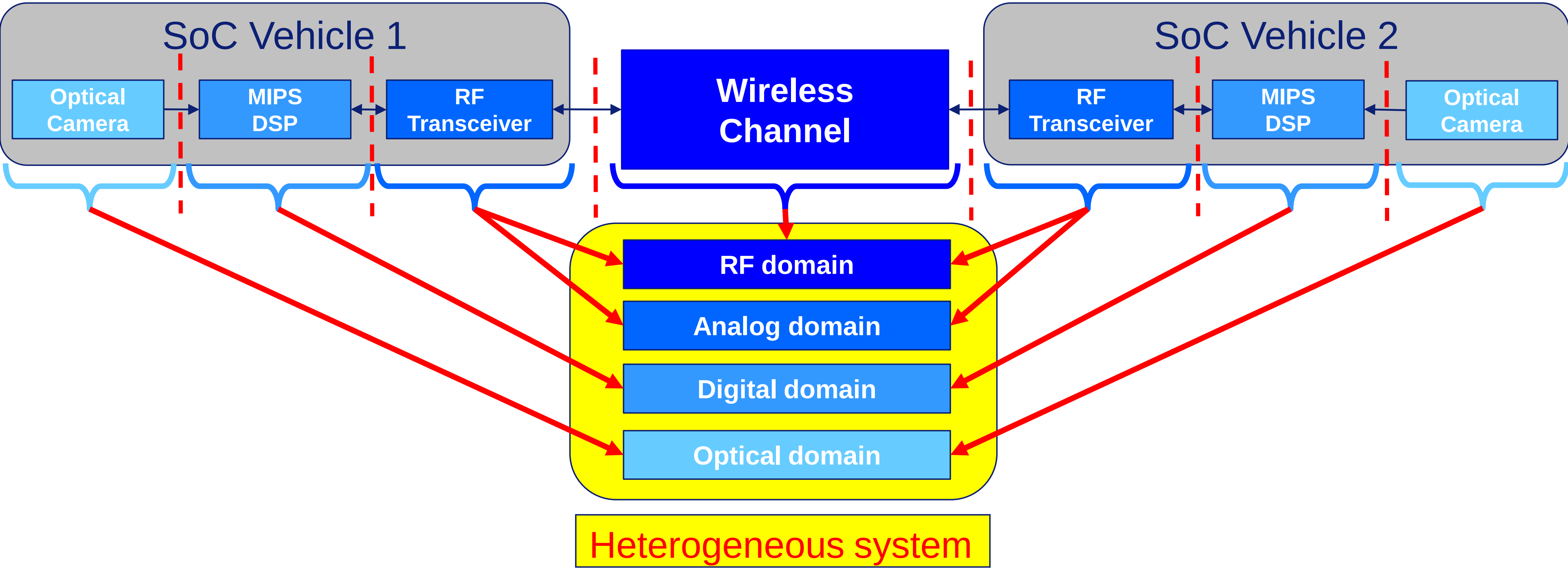
- AMS&RF SoC virtual prototyping and validation through the development of an industrial example: Wireless Video system (WVS).
- Inter-Vehicle Communication





- ❖ What is the efficient behavioral RF model to be used in this complex application?
- ❖ Which tool/programming language should be used to model & simulate this application ?

OUTLINE

- RF models and Modeling language
- Application & Simulation Platform
- Wireless Channel Model
- Simulation results
- Prospects

OUTLINE

- Modeling language: SystemC-AMS
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Which Signal representation of RF Signal?

- Simulations can be done using either passband or complex baseband representation.

Passband

- Pass-band simulations are more accurate
- However, they consume more resources and simulation time.

Baseband

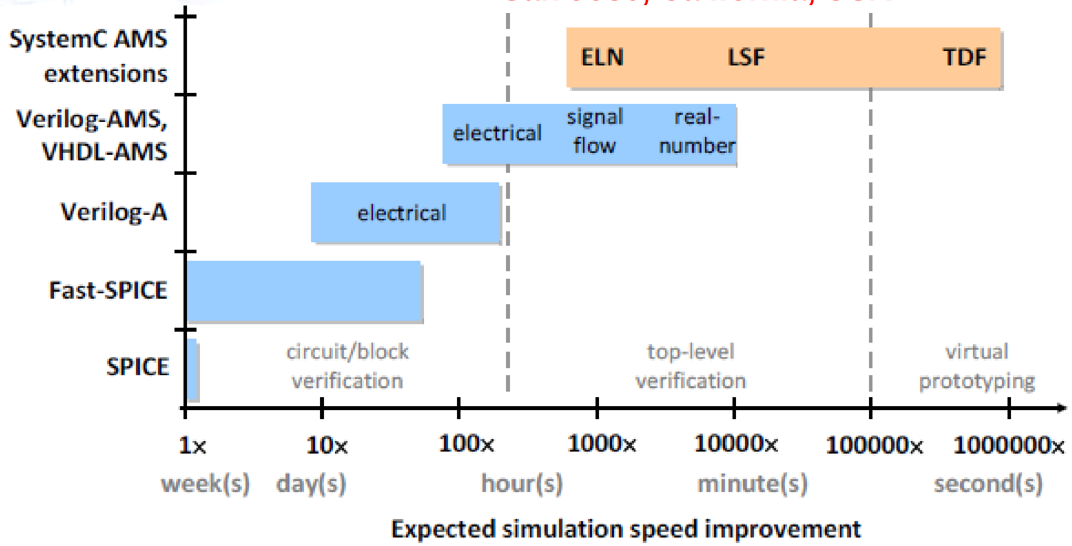
- Baseband models suppress the carrier frequency to trade some accuracy for a dramatic increase in execution speed (they run thousands of times faster than passband models)
- Baseband models allow a generic channel modeling

Baseband behavioral models are used for RF devices and wireless channel

MODELING LANGUAGE SYSTEMC-AMS

❑ Why SystemC-AMS?

➢ According to previous works, it was established that SystemC-AMS is an efffecient tool to deal with the described application



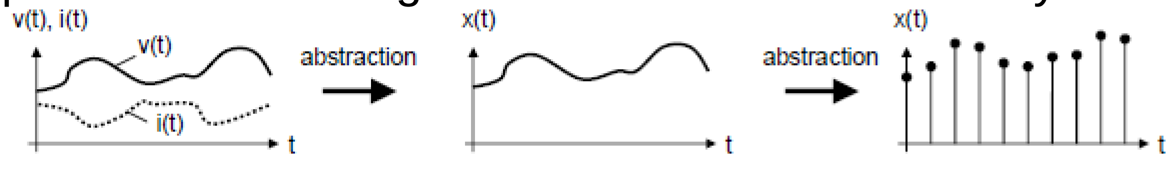
Martin Barnasconi "**SystemC AMS Extensions: Solving the Need for Speed,**" DAC -2010
AMS Working Group Chairman, Open SystemC Initiative, San Jose, CA USA

❑ What is SystemC-AMS?

➢ Analog/Mixed-Signal *(AMS)* standard of the Open SystemC™ Initiative *(OSCI)*
➢ Open Source

❑ Model of Computation

1. **Electrical Linear Networks (ELN) :** used to model continuous time behavior (current & voltage)
2. **Linear Signal Flow (LSF) :** used to model continuous time behavior
3. **Timed Data Flow (TDF) :** facilitates a very effecient simulation, as TDF models are processed at discret time points without using the discret-event kernel of SystemC



a) Electrical Linear Networks b) Linear Signal Flow c) Timed Data Flow

TDF is the SystemC-AMS formalism used in this work

OUTLINE

- Modeling language: SystemC-AMS
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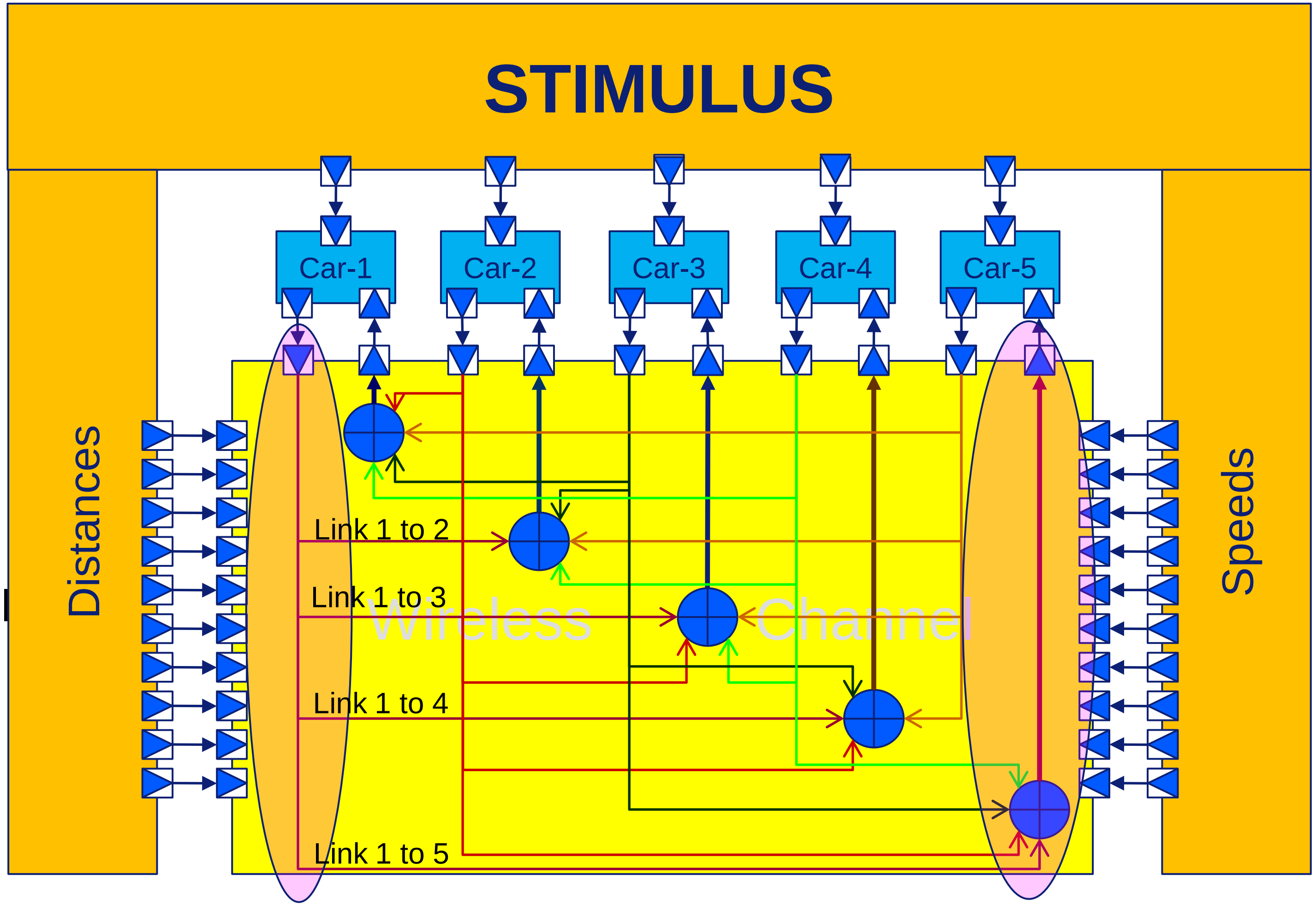
APPLICATION & SIMULATION PLATFORM

- **STIMULUS**
  - o Positions, speeds
- **CAR**
  - o QPSK modulation, Non-linearities, …
- **Wireless Channel**
  - o multipath
  - o Time-varying
  - o Broadcasting characteristics

➢ **20 wireless time-varying channel**

- o **Time and memory consuming**



OUTLINE

- ❑ Modeling language: SystemC-AMS
- ❑ Application & Simulation Platform
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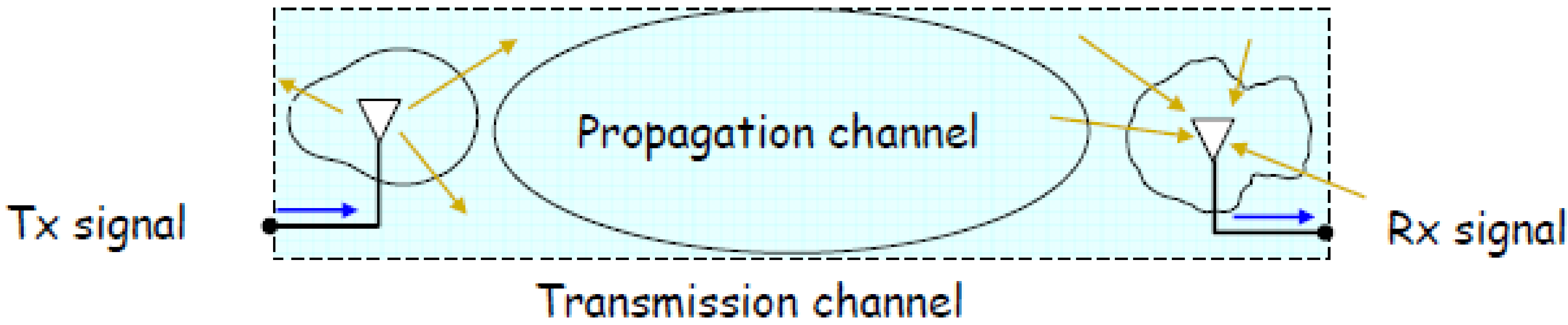
What do we mean by wireless communication channel?

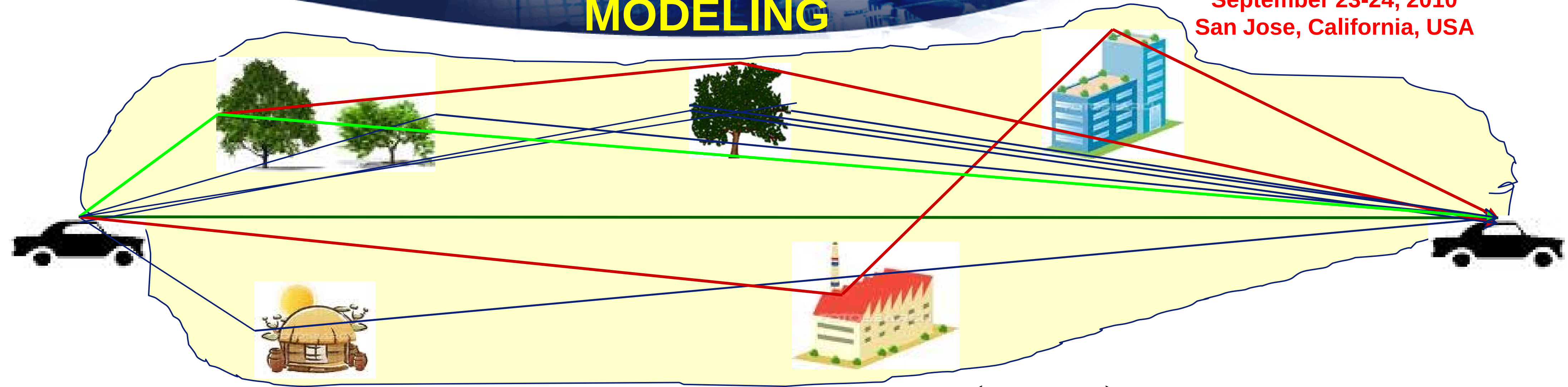
- Transmitter (*Tx*)
- Receiver (*Rx*)



- The transmission channel comprises antennas and all objects contributing or hampering propagation between source and destination nodes
- The propagation channel excludes the antennas and expresses all wave propagation phenomena between Tx and Rx

Transmission channel is considered in this work !!

WIRELESS CHANNEL MODELING



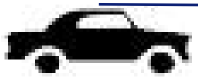
Transmitter (Tx)

Receiver (Rx)

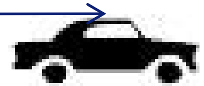
$$y(t) = \left(10^{LdB/10}\right) \cdot \chi \cdot \sum_{k=0}^{K-1} \tilde{g}_k(t).x\left(t - \frac{k}{f_s}\right) + n(t)$$

$$h(t) = \left(10^{LdB/10}\right) \cdot \chi \cdot \sum_{k=0}^{K-1} \tilde{g}_k(t).\delta\left(t - \frac{k}{f_s}\right) + n(t)$$

➢ Node-to-Node Link



$$h(t) = \left(10^{LdB/10}\right) \cdot \chi \cdot \sum_{k=0}^{K-1} \tilde{g}_k(t).\delta\left(t - \frac{k}{f_s}\right) + n(t)$$



Path Loss	Shadowing	Small Scale Fading : Multipath	AWGN
$L_{dB} = 10 \cdot \gamma \cdot \log_{10}\left(d_{Km}\right)$	$\log-normal$ $shadowing$	$h_{MPC}(t) = \sum_{k=0}^{K-1} \tilde{g}_k(t).\delta\left(t - \frac{k}{f_s}\right)$	$n(t)$

Path Loss
- Mean attenuation at a given distance
- Simple
- Short time of simulation

Shadowing
- Environment
- Simple
- Short time of simulation

Small Scale Fading : Multipath
- Reflection, diffraction, diffusion, refraction, ...
- Complex
- Memory Consuming
- Simulation time consuming

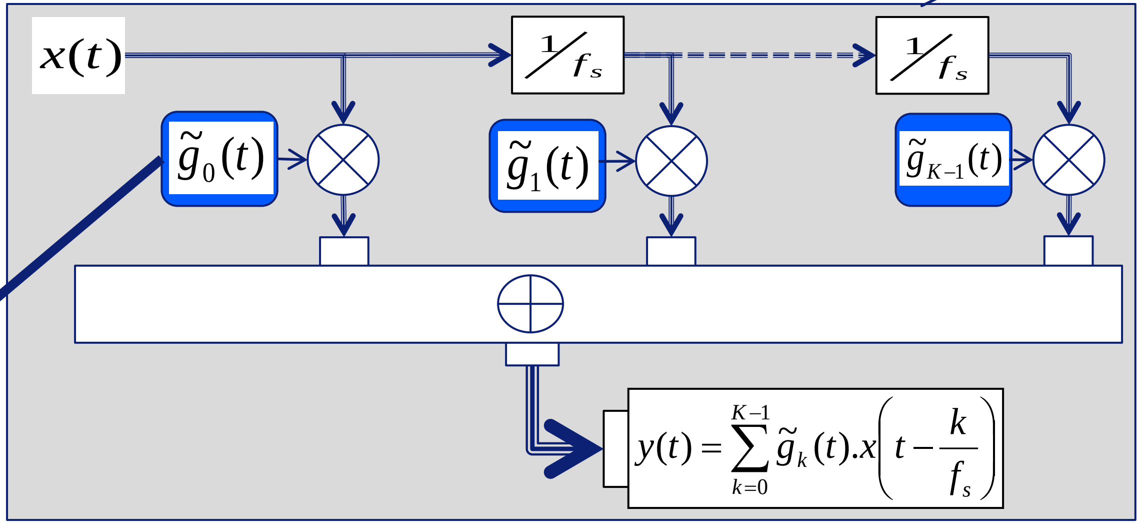
AWGN
- Non-idealities of Antenna
- Simple
- Short time of simulation

Time-varying multipath contribution will be detailed !!

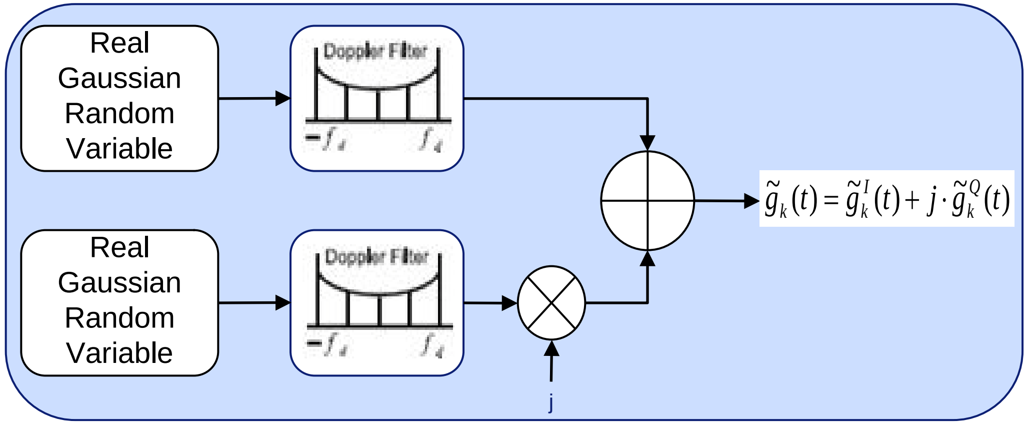
➢ Small Scale Fading Contribution : Multipath propagation

- **Tapped Delay Line (TDL)**
  - o Uniformly spaced model
  - o FIR filter (order K = number of paths)
  - o Coefficients are complex Gaussian variables

$$h_{MPC}(t) = \sum_{k=0}^{K-1} \tilde{g}_k(t).\delta\left(t - \frac{k}{f_s}\right)$$



- **Filtered Gaussian Noise**
  - o 2 independent Gaussian Variables (Box-Muller method)
  - o Time-varying criteria: Doppler filter

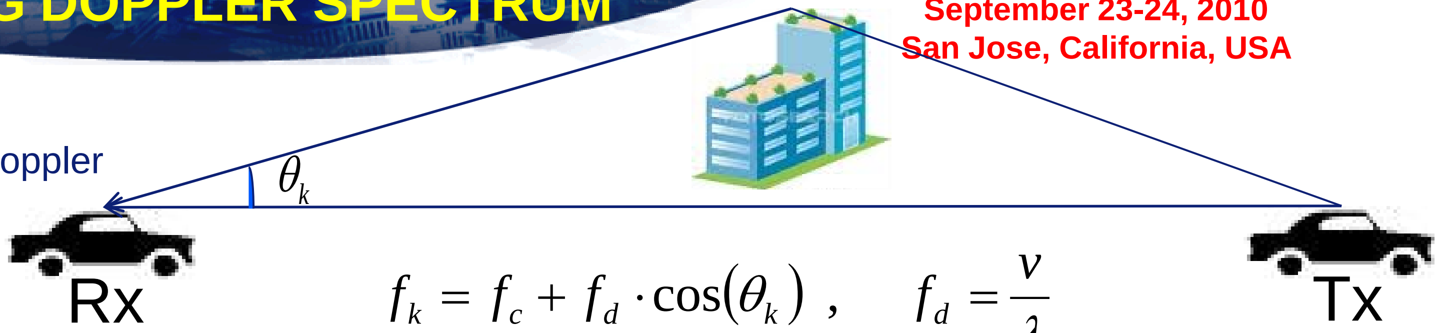


Doppler Filter Design !!

TIME-VARIANT CHANNEL FADING DOPPLER SPECTRUM

❑ Doppler Shift?

- Motion of cars or scatterers produces Doppler shifts of incoming received waves
- **Frequency shift ~ Doppler spread**



$$f_k = f_c + f_d \cdot \cos(\theta_k)\ , \qquad f_d = \frac{v}{\lambda}$$

- Time-varying aspect of the wireless channel is due to this physical phenomenon

❑ Which Doppler Spectrum for Mobile Communication?

- **Jakes, Flat, Gaussian, Rounded, …**

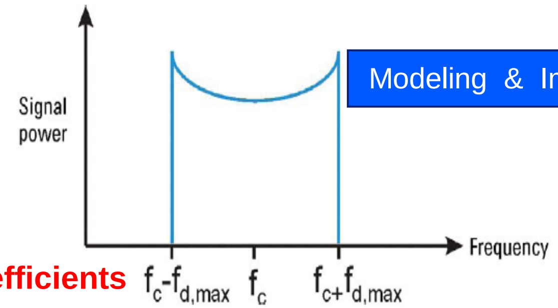
❑ Jakes Doppler Spectrum

- **Spectrum**
- **Amplitude frequency**
- **Power Spectrum: « U Shape »**

$$S(f) = \frac{1}{\pi f_d \sqrt{1-(f/f_d)^2}},\ |f| \le f_d$$

$$\Downarrow$$

$$H(f) = \sqrt{S(f)}$$



Modeling & Implementation

- **FIR Filter (High order)**
- **IIR Filter (Stability problem)**
  - o **Butterworth**
  - o **Chebuchev Type-I/II**
  - o **Elleptic (attenuation in the stop band,No ripple in stop band)**

- ❑ **f_d<<f_s**
- ❑ **cut-off frequency is sharp**
- ❑ **Frequency-domain: (simple, but all the channel coefficients must be generated in the beginning of the simulation)**
- ❑ **Time-domain: (complex, but it has the real-time aspect of wireless communication)**

WIRELESS CHANNEL : *SYSTEMC-AMS* IMPLEMENTAION

Small Scale Fading: SystemC-AMS Implementation

```
#ifndef SMALL_SCALE_FADING_H
#define SMALL_SCALE_FADING_H

#include "compute_ssf.h  "

SCA_TDF_MODULE(small_scale_fading)
{
    sca_tdf::sca_in < complex<double> > in;
    sca_tdf::sca_out < complex<double> > out;
    sca_tdf::sca_in < double > v;

    public :
        //Doppler filter parameters
        double Ap;      // Band pass ripple in dB
        double As;      // Stop band ripple in dB
        double fp;      // Band pass edge frequency (maximum doppler shift in Hz)
        double fs;      // sampling frequency in Hz
        double fc;      // Carrier frequency in Hz

        compute_ssf *compute_ssf_inst;

    void processing(void)
    {
        this->fp = 3.6*v.read()*fc/speed_light;
        complex<double> yt =  compute_ssf_inst->compute(in.read(),v.read());
        out.write(yt);
    }

    SC_CTOR(small_scale_fading)
    {
        this->Ap = 0.5;
        this->As = -80;
        this->fs = 160e6;
        this->fc = 5.9e9;
        compute_ssf_inst = new  compute_ssf(Ap, As, fp, fs, fc);
    }
};
#endif // SMALL_SCALE_FADING_H
```

- *Small_scale_fading* TDF module declaration
- TDF Input & Output ports : Complex baseband signals
- TDF Input port : Vehicular Speed (used to compute Doppler shift)
- Atrributes (used to compute the Doppler filter coefficients)
- *Compute_ssf* class (it implements the multipath contribution)
- Processing method (invoked at each sample time)
- Apply the multipath contribution on the input signal to get the output one
- Constructor of the *small_scale _fading* TDF module
- Atrributes initiatialization and *compute _ssf* object instantiation

WIRELESS CHANNEL : *SYSTEMC-AMS* IMPLEMENTAION

❑ *Node-to-Node Link*: SystemC-AMS Implementation (*Netlist*)

```
#ifndef NODE_TO_NODE_LINK_H
#define NODE_TO_NODE_LINK_H

#include "pathloss/pathloss.h"
#include "small_scale_fading/small_scale_fading.h "
#include "awgn/awgn.h "

SC_MODULE (node_to_node_link)
{
   sca_tdf::sca_in < complex<double> > in;
   sca_tdf::sca_out < complex<double> > out;
   sca_tdf::sca_in < double > d;
   sca_tdf::sca_in < double > v;

   sca_tdf::sca_signal < complex<double> > sig1;
   sca_tdf::sca_signal < complex<double> > sig2;

   pathloss *pathloss_inst1;
   small_scale_fading *small_scale_fading_inst1;
   awgn *awgn_inst1;

   SC_CTOR(node_to_node_link)
   {
      pathloss_inst1 = new pathloss("pathloss_inst1");
      small_scale_fading_inst1 = new small_scale_fading("small_scale_fading_inst1");
      awgn_inst1 = new awgn("awgn_inst1");

      pathloss_inst1 -> in(in);
      pathloss_inst1 -> out(sig1);
      pathloss_inst1 ->  d(d);
      small_scale_fading_inst1 -> in(sig1);
      small_scale_fading_inst1 -> out(sig2);
      small_scale_fading_inst1 -> v(v);
      awgn_inst1 -> in(sig2);
      awgn_inst1 -> out(out);
   }
};
#endif // NODE_TO_NODE_LINK_H
```

- ❑ *node_to_node* TDF module declaration
- ❑ TDF Input & Output ports : Complex baseband signals
- ❑ TDF Input port : Vehicular Speed (used to compute Doppler shift) & distance (used to calculate attenuation)
- ❑ TDF signals (used to interconnect TDF modules)
- ❑ *Pathloss, smale_scale_fading,* and *awgn* module declaration (wireless channel contributions)
- ❑ Constructor of the *node_to_node* TDF module
- ❑ *Pathloss, smale_scale_fading,* and *awgn* module instantiations
- ❑ Netlist of wireless channel contributions (TDF modules interconnect)

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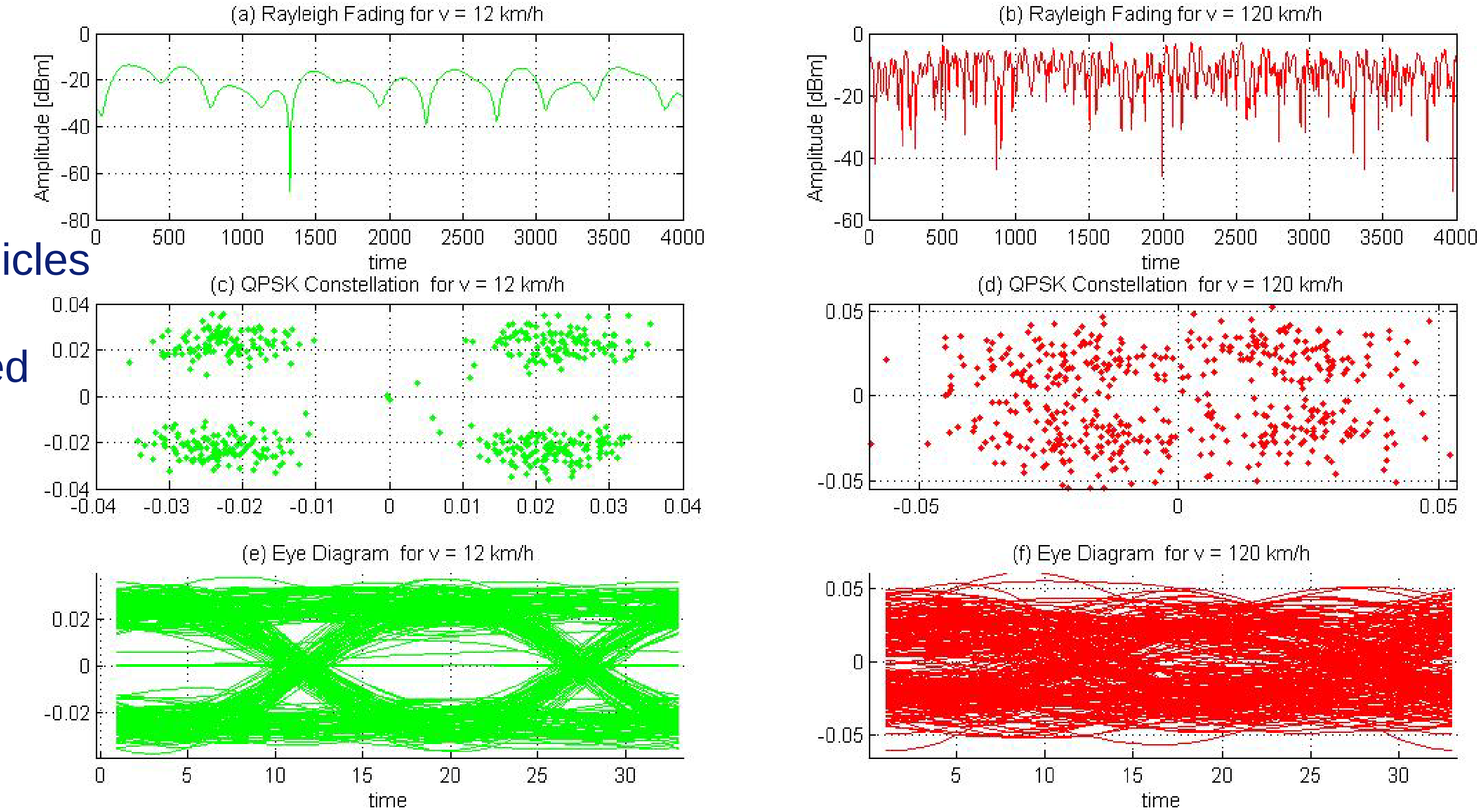
SIMULATION RESULTS

➢ System Performance Simulation results

- ❑ Fading channel
- ❑ QPSK constellation
- ❑ Eye diagram

- ❑ The faster are the vehicles
- ➢ The more the system Performances are effected

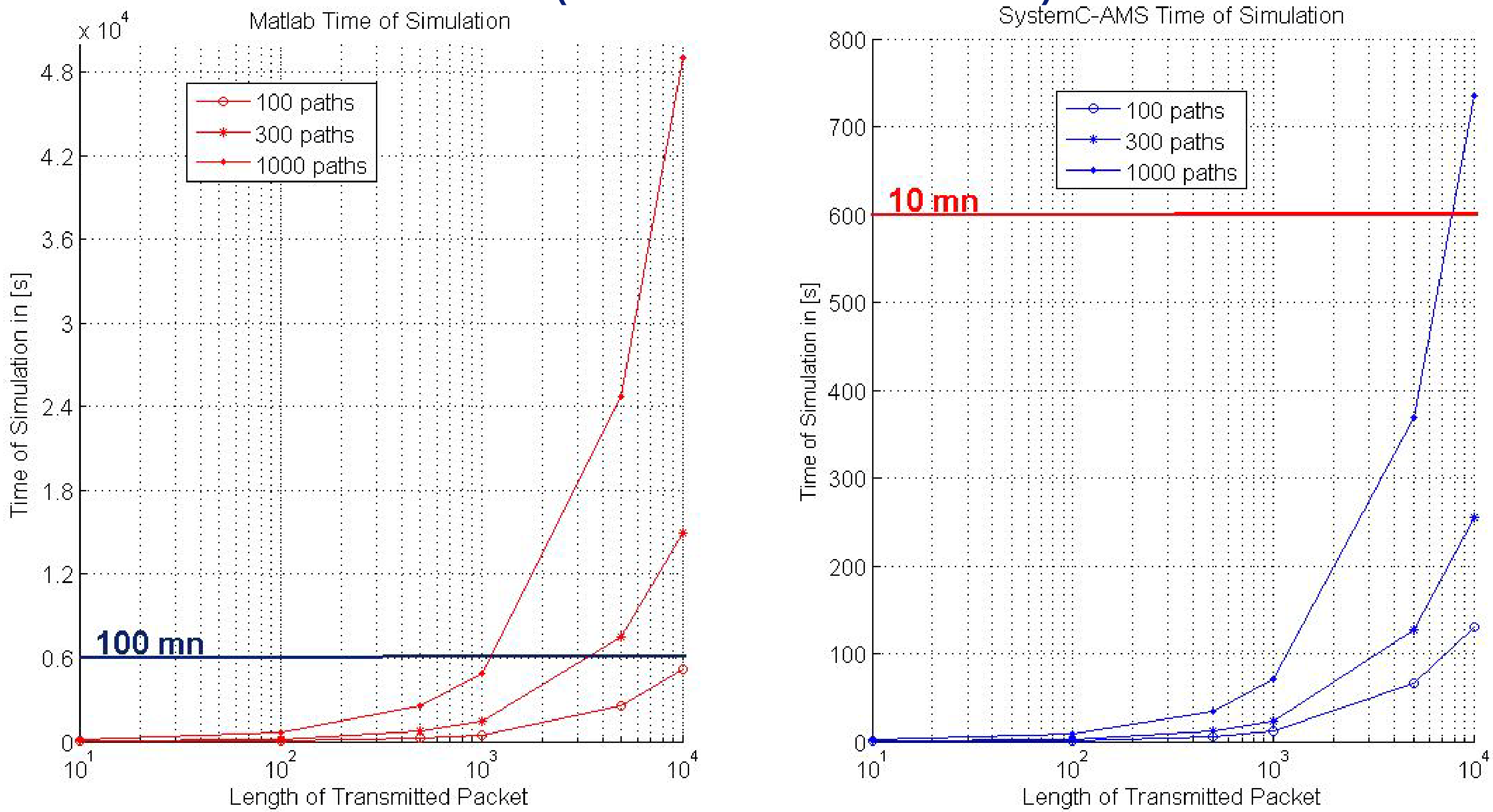


- ❑ Bit Error Rate, …

SIMULATION RESULTS

➢ Simulation Speed Enhancement

- ❖ **Linux Ubuntu machine:** 1) Dual 64 bit 2.4GHz Intel Xeon processors, 2) 12GB memory
- ❖ **5 vehicles scenario, 20 time-varying wireless channel**
- ❖ **TDMA protocol to avoid multi-access interferences**
- ❖ **Total time of simulation : 50 Time Slots (10 transmissions for each car)**



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SUMMARY

- **Wireless channel was modeled and implemented using SystemC-AMS for virtual prototyping of AMS&RF SoC**
- **SystemC-AMS is an effecient tool to simulate Heteregeneous System**
- **TDF formalism is accurate and it speeds up simulation**

- **Add Channel coding and decoding processing to the current toolbox**
- **Perform Time-domain Equalization in order to combat Inter-Symbol Interference**
- **Perform High level power estimation**

Thank you for your Attention