Intelligent Transport driven by IoT

Prof. Hai L. Vu

ARC Future Fellow and Head, Intelligent Transport Systems Lab

Swinburne Univ. of Technology

The ITS Lab

www.swinburne.edu.au/science-engineering-technology/research/intelligent-transport-systems-lab/

SWINBURNE UNIVERSITY OF TECHNOLOGY

Faculty of Science, Engineering and Technology

- Science, Engineering and Technology Home
- Courses and Study Areas
- Schools
- Current Students
- Mathematics and Statistics Help (MASH) Centre
- Industry Engagement
- Research
  - Find a researcher or supervisor
  - PhD Research Topics
- Staff Profiles
- Executive Dean's Welcome
- Contact Us
- Staff Intranet

> Faculty of Science, Engineering and Technology > Research > Research Institutes & Centres

Intelligent Transport Systems Lab (ITSL)

The Intelligent Transport Systems Lab (ITLS) conducts multi-disciplinary collaborative research to address urban congestion and to enable more sustainable future transportation through both efficient use of infrastructure and better demand management.

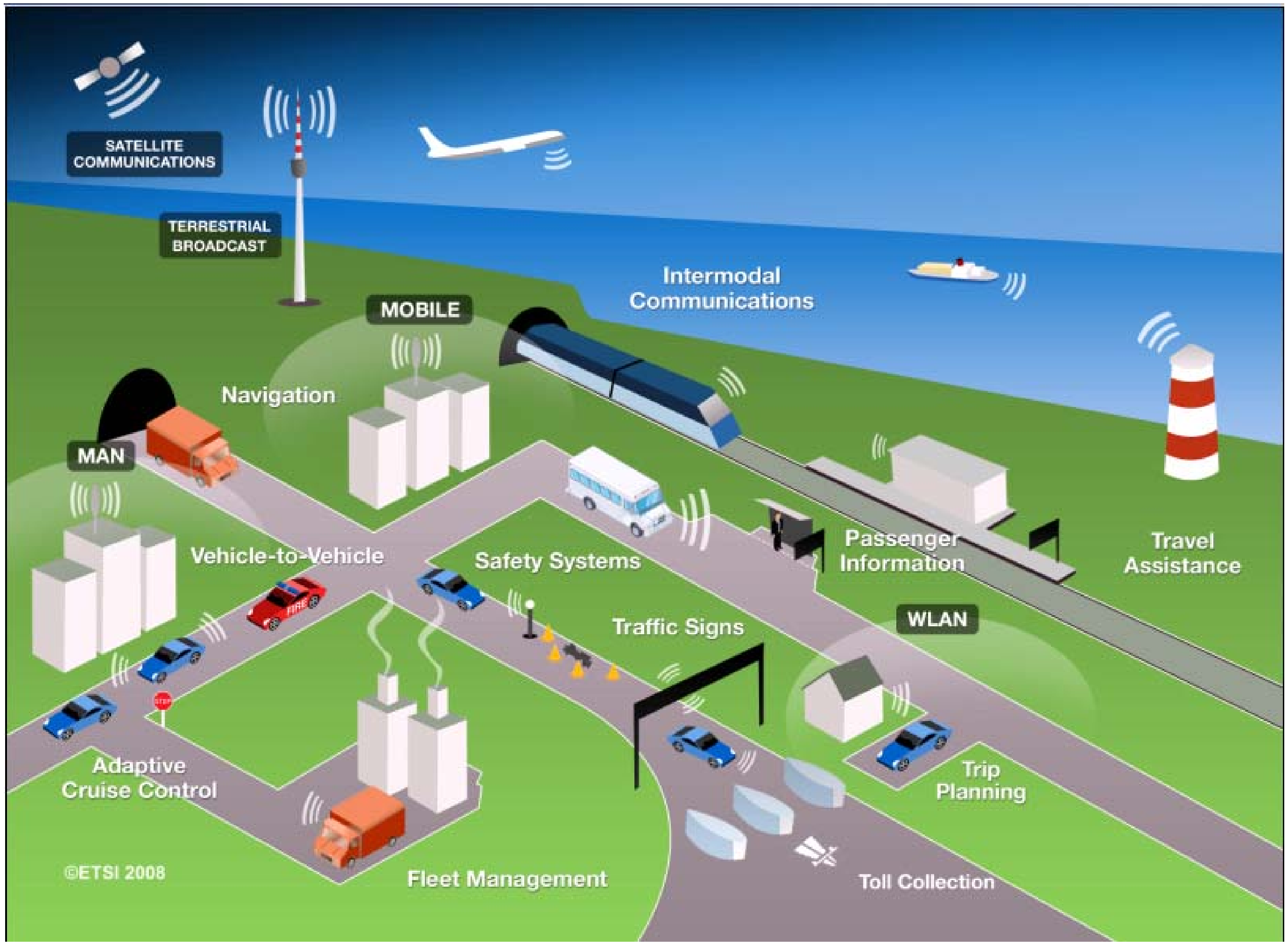
The ITSL, based at the Swinburne Hawthorn campus, was established in partnership with VicRoads in 2012 and represents a strategic partnership between universities, research institutions, government agencies and industry to conduct R&D in smart information use to improve traffic flows, and provide better informed and better managed transport systems for Victoria and Australia.

The Swinburne ITSL team brings together research expertise in networks and data communication, artificial intelligence, big data analytics and the modelling of data intensive systems, their management and control. The team also has expertise in sustainable infrastructure and transportation.

› **Capability Statement [PDF 77KB]**

- **Partner Organisations**
- **Research**
- **Staff**
- **Publications**
- **In the media**
- **Swinburne ITS demos and products**

Intelligent Transport Systems (ITS)



Source: www.etsi.org/WebSite/document/Technologies/ETSI-ITS.jpg

IoT and Intelligent Transport

- Many sensors are in the transport infrastructure
- Users (equipped with wireless devices) also provide valuable information

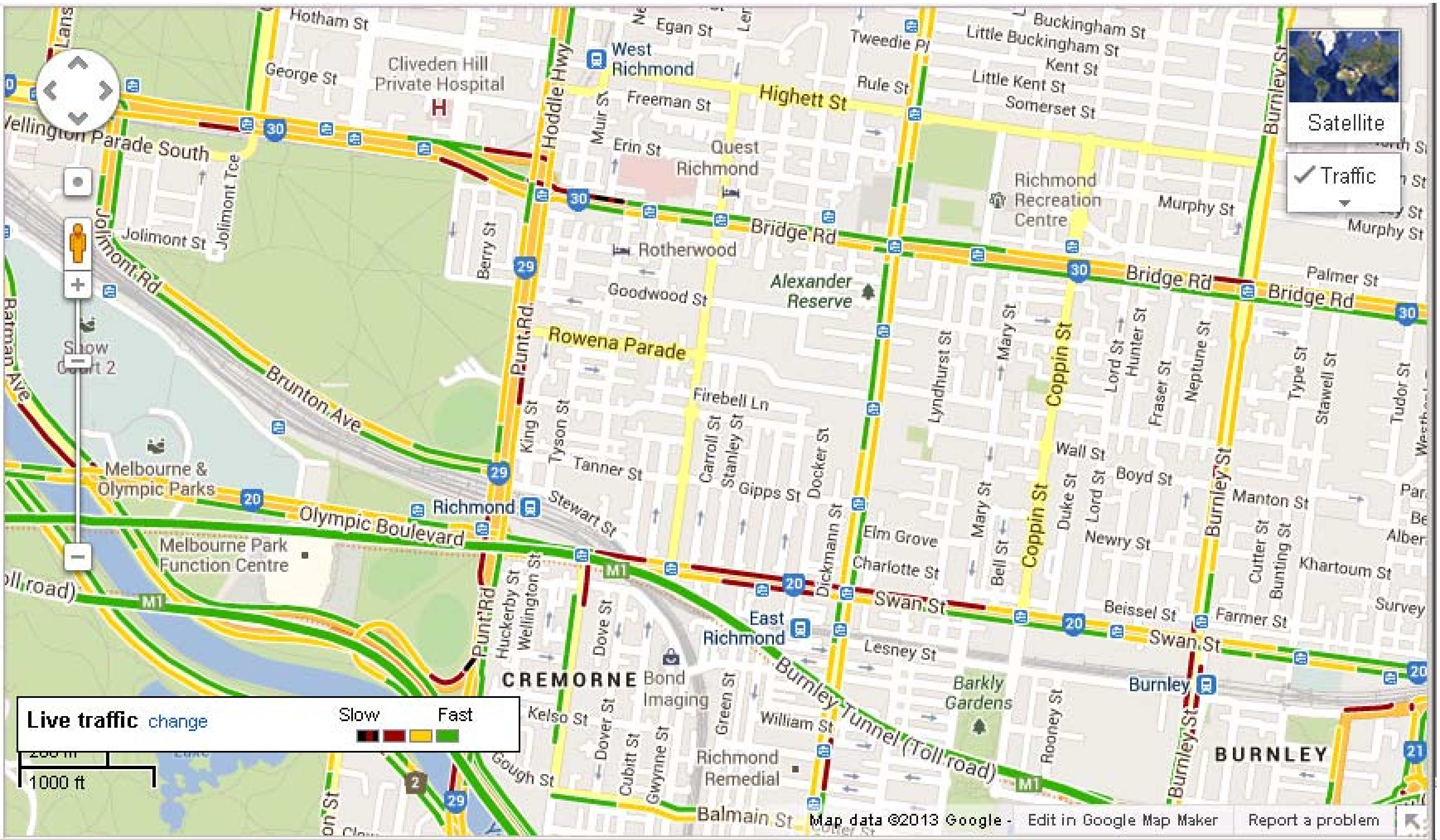
Vast amount of information is available

What “**having information”** actually means?

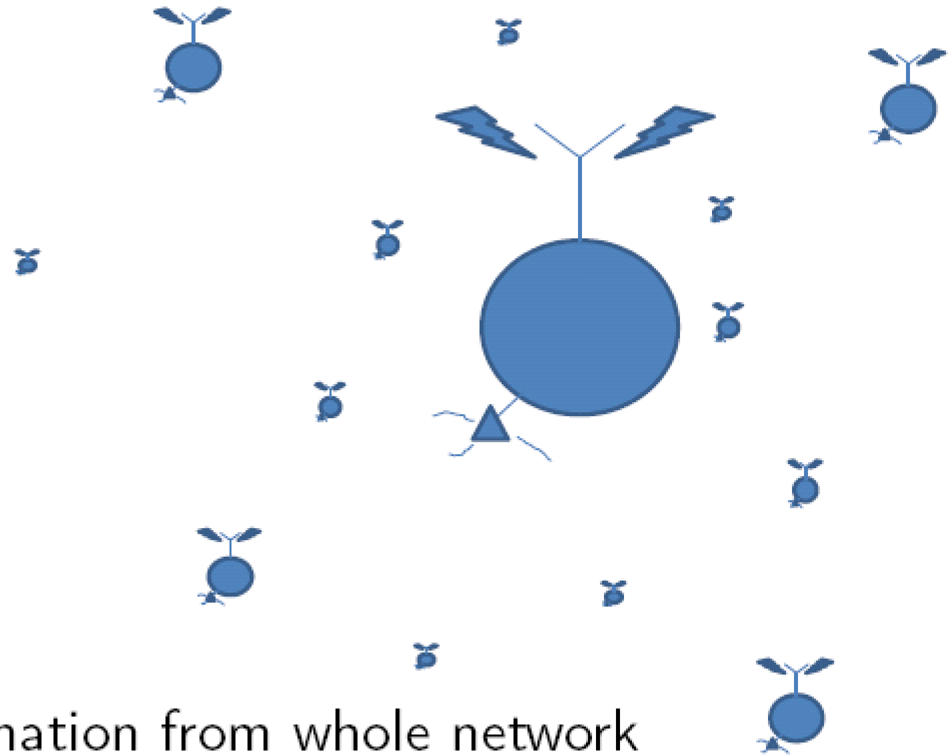
Connected vehicles in ITS (V2V)

Source: www.extremetech.com

Traffic map by V2V gossiping



The Age of Information (AoI)



Nodes:

- Sense
- Transmit
- Receive
- Gossip
- Are users of information from whole network

Goal: Performance analysis and control with respect to

$$X(i,j) = \textbf{the age of } j\textbf{-info at node } i$$

for all node pairs i, j

AoI: Definition

$$X_{n+1}(i,j) = \begin{cases} \left(X_n(i,j) \wedge \bigwedge_{\{k: R_n(k,i) U_n(k,j)=1\}} X_n(k,j)\right) + 1 & i \neq j, \\ 0 & i = j. \end{cases}$$

- $i, j \in \{1, \ldots, M\}$
- Discrete time, $n = 0, 1, 2, \ldots$
- **State** $X_n(i,j)$ is age of the the j-info at node i
- **Control** $U_n(k,j)$ is indicator of j-info in message from k
- $T_n(k) = \mathbf{1}_{\{\sum_{j=1}^{M} U_n(k,j) \geq 1\}}$ is indicator of message transmit at k
- **Environment** $R_n(k,i)$ is indicator of reception at i of message from k. Can only equal 1 if $T_n(k) = 1$

AoI: Model

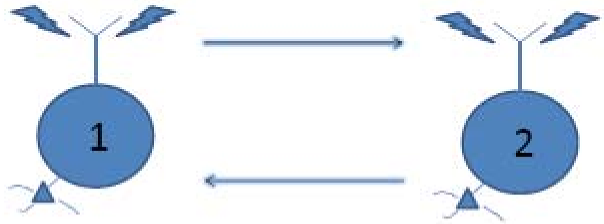
Bernoulli channels: $R_n(\cdot,\cdot)$ are "i.i.d" depending only on transmissions in current time: $\Big(T_n(1),\dots,T_n(M)\Big)$
Local Bernoulli policies: $U_n(\cdot,\cdot)$ are i.i.d not depending on anything yet with possible constraints such as $\sum_{j=1}^{M} U_n(i,j) \le K$

This makes $\{X_n\}_{n=0}^{\infty}$ a Markov chain on state space $\mathbb{Z}_+^{M\times M} \setminus M$

The following performance measures are of interest:

$$\pi_\ell(i,j) = \lim_{n\to\infty} P\Big(X_n(i,j)=\ell\Big), \quad m(i,j) = \sum_{\ell=0}^{\infty} \ell\, \pi_\ell(i,j).$$

AoI: simplest non-trivial example



$q_1, q_2 \in (0,1)$: probs' of Tx.
$p_1, p_2 \in (0,1)$: probs' of Rx without interference
$p_{1*}, p_{2*} \in (0,1)$: probs' of Rx with interference (during Tx)

$\{X_n\}_{n=0}^{\infty}$ is a Markov chain on $\mathbb{Z}_+^2$ with four types of transitions:

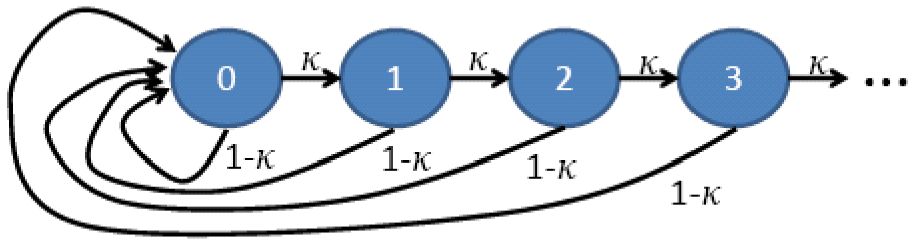
Event	State Change	Probability
no Rx	$(++1, \quad ++1)$	$\lambda(\emptyset) = \bar{q}_1\bar{q}_2 + q_1\bar{q}_2\bar{p}_2 + \bar{q}_1 q_2\bar{p}_1 + q_1 q_2\bar{p}_{2*}\bar{p}_{1*}$
Rx 1 only	$(=1, \quad ++1)$	$\lambda(1) = \bar{q}_1 q_2 p_1 + q_1 q_2 p_{1*}$
Rx 2 only	$(++1, \quad =1)$	$\lambda(2) = q_1\bar{q}_2 p_2 + q_1 q_2 p_{2*}$
Rx both	$(=1, \quad =1)$	$\lambda(1,2) = q_1 q_2 p_{2*} p_{1*}$

AoI: Marginal

Look first at marginal distributions,

$$\tilde{\pi}_{\ell_1,\cdot} = \sum_{\ell_2=0}^{\infty} \tilde{\pi}_{\ell_1,\ell_2}, \quad \tilde{\pi}_{\cdot,\ell_2} = \sum_{\ell_1=0}^{\infty} \tilde{\pi}_{\ell_1,\ell_2},$$

The associated Markov chains are well known:



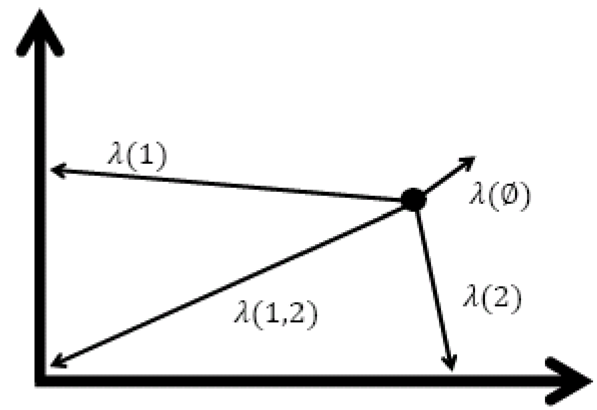
For the i'th marginal ($i = 1, 2$), take $\kappa = c_i = \lambda(\emptyset) + \lambda(i)$

Balance equations are:

$$\hat{\pi}_\ell = \kappa \hat{\pi}_{\ell-1}, \quad \ell = 1, 2, \ldots.$$

as well as $\sum_{\ell=0}^{\infty} \hat{\pi}_\ell = 1$.

AoI: Full distribution



Look now at the balance equations:

$$\pi_{0,0} = \lambda(1,2) \sum_{\ell_1,\ell_2} \pi_{\ell_1,\ell_2},$$

$$\pi_{\ell_1,0} = \lambda(2) \sum_{\ell_2=0}^{\infty} \pi_{(\ell_1-1),\ell_2} \quad , \ell_1 \geq 1,$$

$$\pi_{0,\ell_2} = \lambda(1) \sum_{\ell_1=0}^{\infty} \pi_{\ell_1,(\ell_2-1)} \quad , \ell_2 \geq 1,$$

$$\pi_{\ell_1,\ell_2} = \lambda(\emptyset)\pi_{(\ell_1-1),(\ell_2-1)} \quad , \ell_1, \ell_2 \geq 1.$$

Knowledge of the marginals gives us the solution

AoI: Insights

In the previous example we saw that the stationary distribution can be expressed in terms of the marginal distributions

It turns out that this is also the case for more complicated examples

We can exploit this relationship for efficient numeric computation of more complicated examples

Conclusion

- More and more information is available (fuelled by IoT)
- It can be very beneficial for area such as ITS
- But there are still challenges in the understanding and use of information
- Our research is driven by this very challenge !

Acknowledgments

• Hai L. Vu is supported by the ARC Future Fellowship grant (FT120100723)

• This work was done in collaboration with Yoni Nazarathy (UQ), Lachlan Andrew (Monash) and Jori Selen (Eindhoven Univ.)