BATS: A Revolutionary Wireless Technology for Smart Hong Kong

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Smart City

- Integrate intelligent technologies with the natural and built environments
- Improve a city's social, economic, and environmental sustainability and quality of life of residents

Smart Lampposts

- Key infrastructure of smart cities
- Equipped with networking interfaces, cameras and sensors
- Promote smart city innovations on a city scale
  - intelligent transportation
  - autonomous driving
  - real-time surveillance
  - high-speed WiFi coverage
- Estimated over 70 million smart lampposts will be installed worldwide by 2027
- Creating a global market of USD $8.3 billion

Smart Lamppost Connectivity

- Smart lampposts must be connected to the Internet backbone
- Possible technologies
  - optical fiber
  - 5G
  - BATS

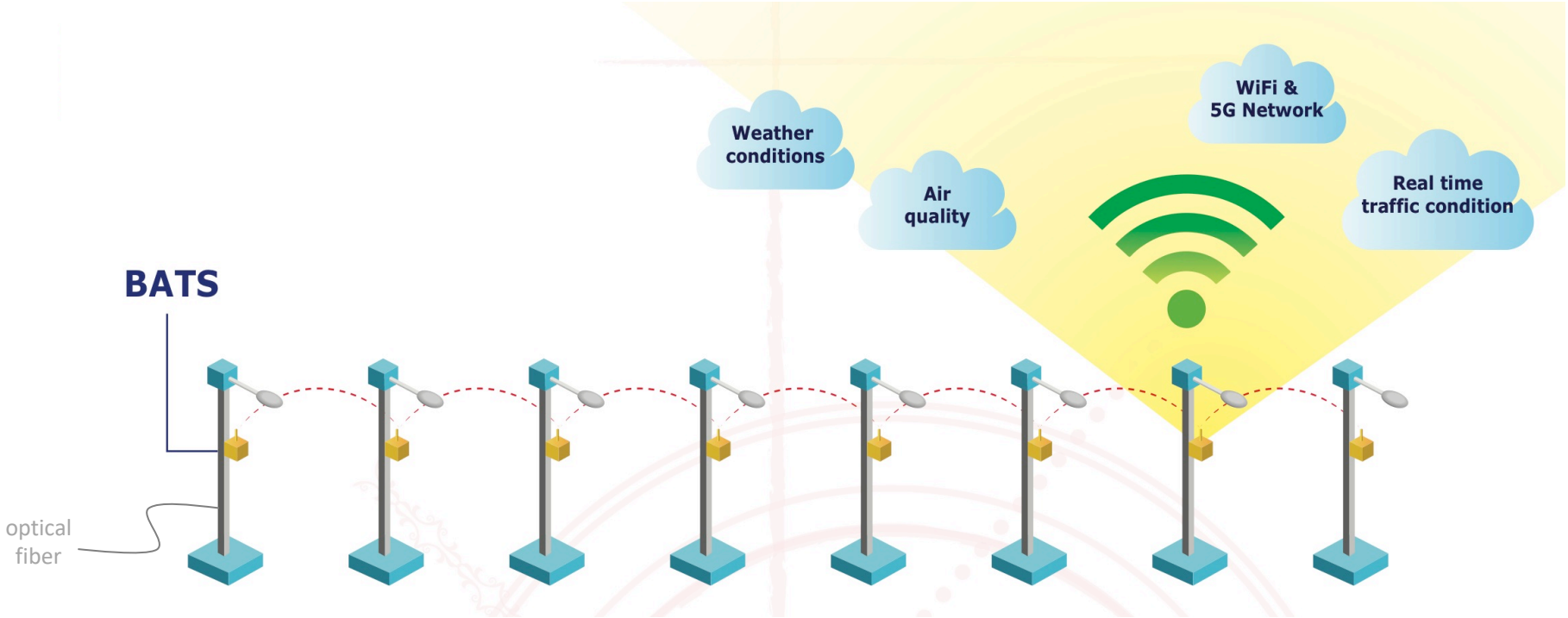
Optical Fiber

- Pros
  - very high data rate
  - highly reliable
- Cons
  - high installation cost
  - very long setup time
  - very disrupting process
  - sometimes not possible
- Realistically only a small number of lampposts can be connected by optical fiber
- The rest still need to be connected to the Internet

How about 5G?

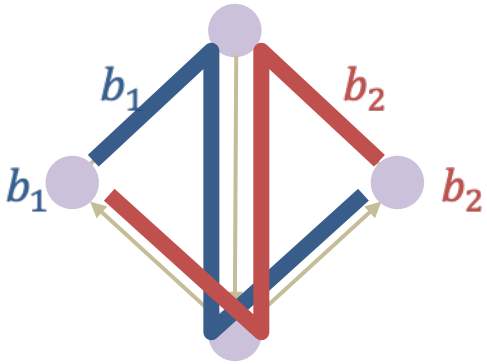
- A 5G card is installed at each lamppost
- Pros
  - easy to deploy
  - relatively inexpensive
- Cons
  - high recurrent cost
  - 1Mbps = 2.5Tb per month

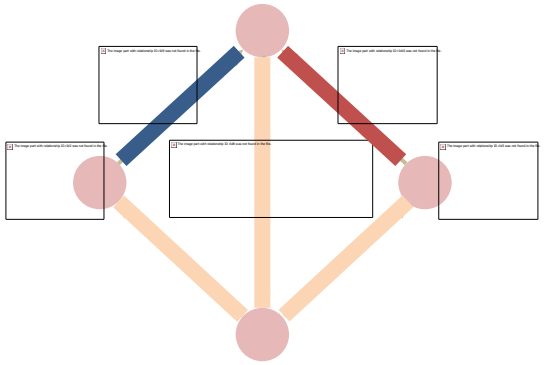
Introducing the Multi-hop Solution



A Network Coding Example

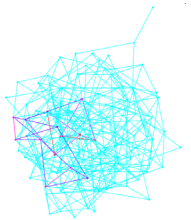
$$b_1 + b_2 = \begin{cases} 0 & \text{if } b_1 = b_2 \\ 1 & \text{if } b_1 \neq b_2 \end{cases}$$



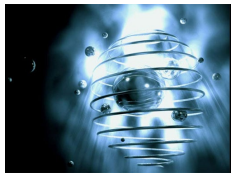


Information is NOT a commodity !

Network coding is required to achieve optimality.



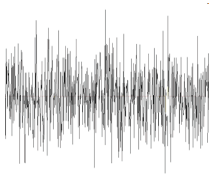
Graph theory



Quantum information theory

Information theory

Channel coding



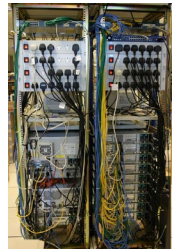
Wireless networks

Optimization theory

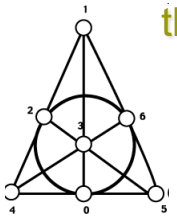
Game theory

Computer networks

Switching theory



Matroid theory



Cryptography

Computer science

Data storage

International Recognitions

2005 IEEE Information Theory Society Paper Award

2016 IEEE Eric E. Sumner Award

2018 ACM SIGMOBILE Test-of-Time Paper Award

2019 Gold Medal with Congratulations of the Jury, the 47th International Exhibition of Inventions of Geneva

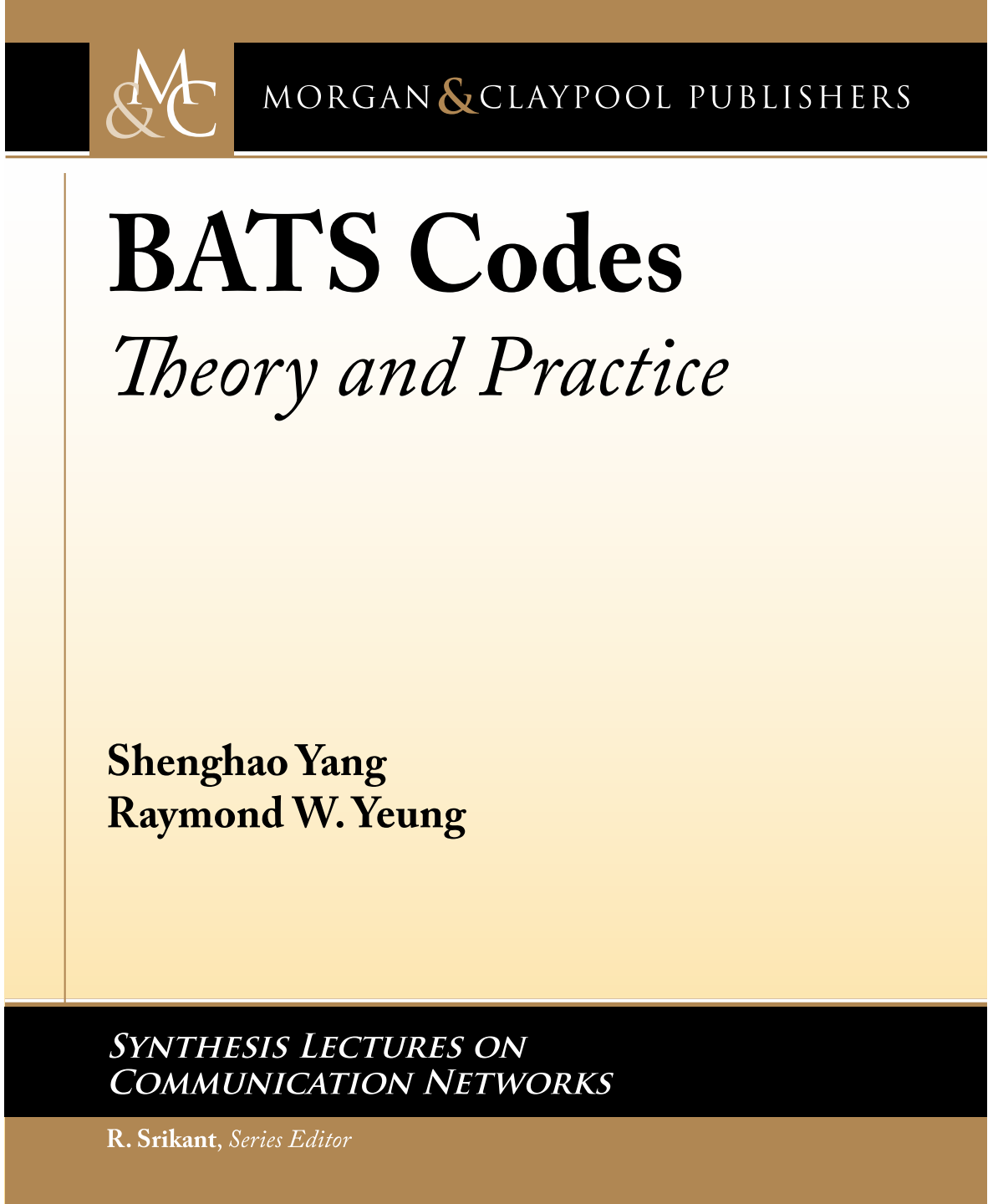
2021 IEEE Richard W. Hamming Medal – a highest honour in Electrical Engineering

2022 Claude E. Shannon Award – the highest honour in Information Theory

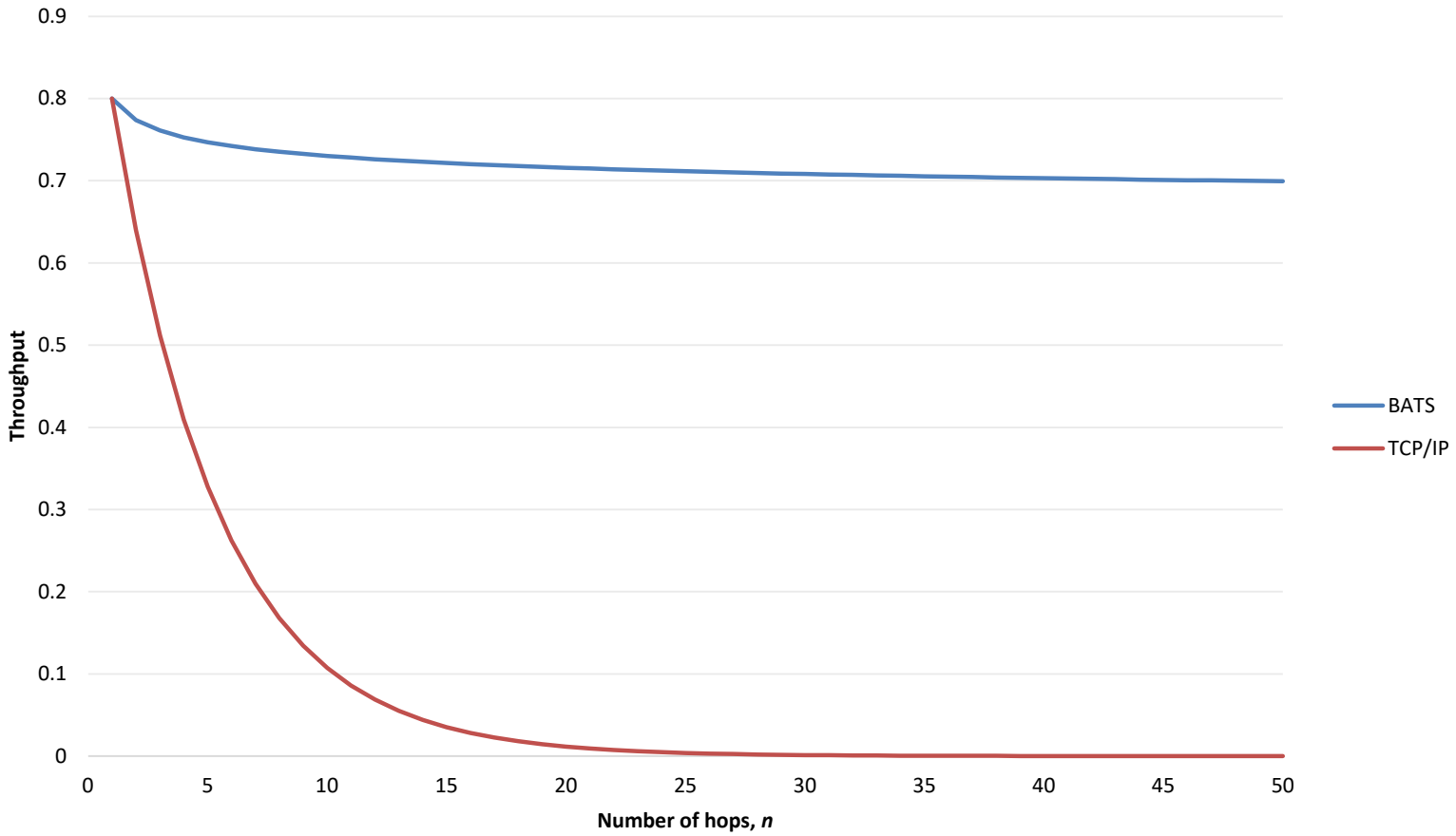
For fundamental contributions to information theory and pioneering network coding and its applications

Why BATS?

- Multi-hop is a longstanding problem in wireless communication
- Transmission can sustain no more than a few hops if data packets are treated as commodities
- The multi-hop curse
- **BATS** is an advanced network coding technology that can sustain tens or even hundreds of hops
- Recoding is employed at the intermediate nodes
- With **BATS**, a very long multi-hop network can be realized


MORGAN & CLAYPOOL PUBLISHERS
BATS Codes
Theory and Practice
Shenghao Yang
Raymond W. Yeung
SYNTHESIS LECTURES ON
COMMUNICATION NETWORKS
R. Srikant, Series Editor

Performance Comparison



Prototype

- 11 hops
- BATS vs Fountain Code
- Video demo:

http://iest2.ie.cuhk.edu.hk/~whyeung/Side-by-side_2.5Mbps.mov

Operational Advantages of BATS

- Low installation cost
- Rapid deployment without the need to lay new fibre
- Low recurrent cost
- High security (data randomized, dedicated network)
- Can cover rural areas not reachable by fiber or 4G/5G

BATS in Smart Hong Kong

Hong Kong Smart Lamppost Project

- Successfully deployed BATS in 36 smart lampposts in East Kowloon
  - 常悦道, 承啟道, 裕民坊
- The general public has concern about the installation of video cameras on the lampposts due to possible infringement of privacy
- Will resume by end of 2021, with video cameras replaced by LiDARs

- Participated in the 47th International Exhibition of Inventions of Geneva, 2019:

  "Wireless Multi-hop Network for Smart Lampposts"

- Awarded a Gold Medal with Congratulations of the Jury

DIPLÔME

Inventions Geneva

SALON INTERNATIONAL DES INVENTIONS

GENÈVE

Après examen, le Jury International a décidé

de remettre à: Shenghao Yang, Raymond W. Yeung, Raymond Chan Kwong Wing

pour l'invention: BATS, technologie sans fil capable d'offrir aux lampadaires intelligents une connectivité Internet à large bande passante sans avoir à poser de nouvelles fibres optiques.

MÉDAILLE D'OR
GOLD MEDAL
GOLDMEDAILLE

Genève, le 12 avril 2019

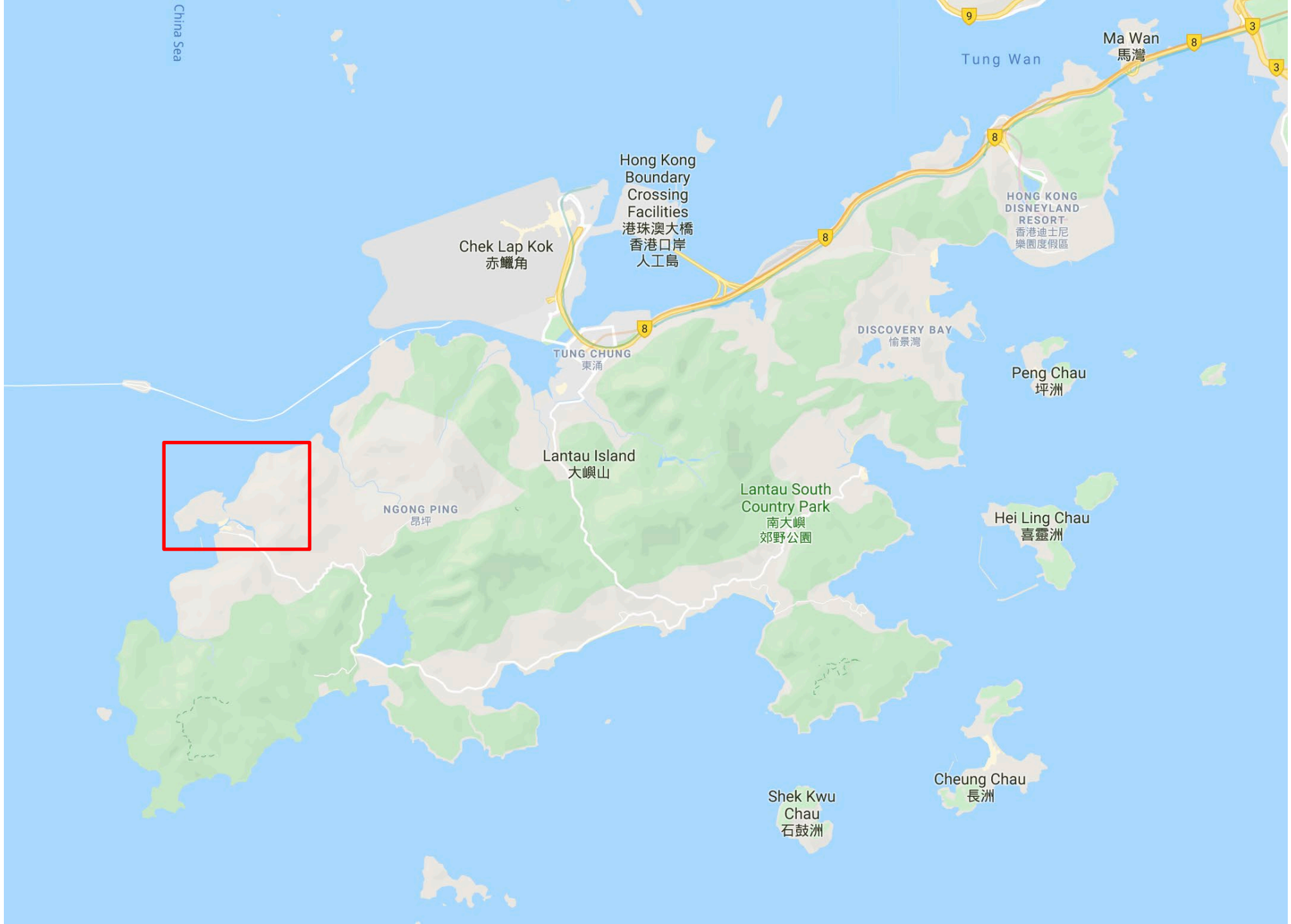
Avec les félicitations du jury
With the congratulations of the jury
Mit höchsten Empfehlungen des Preisgerichtes

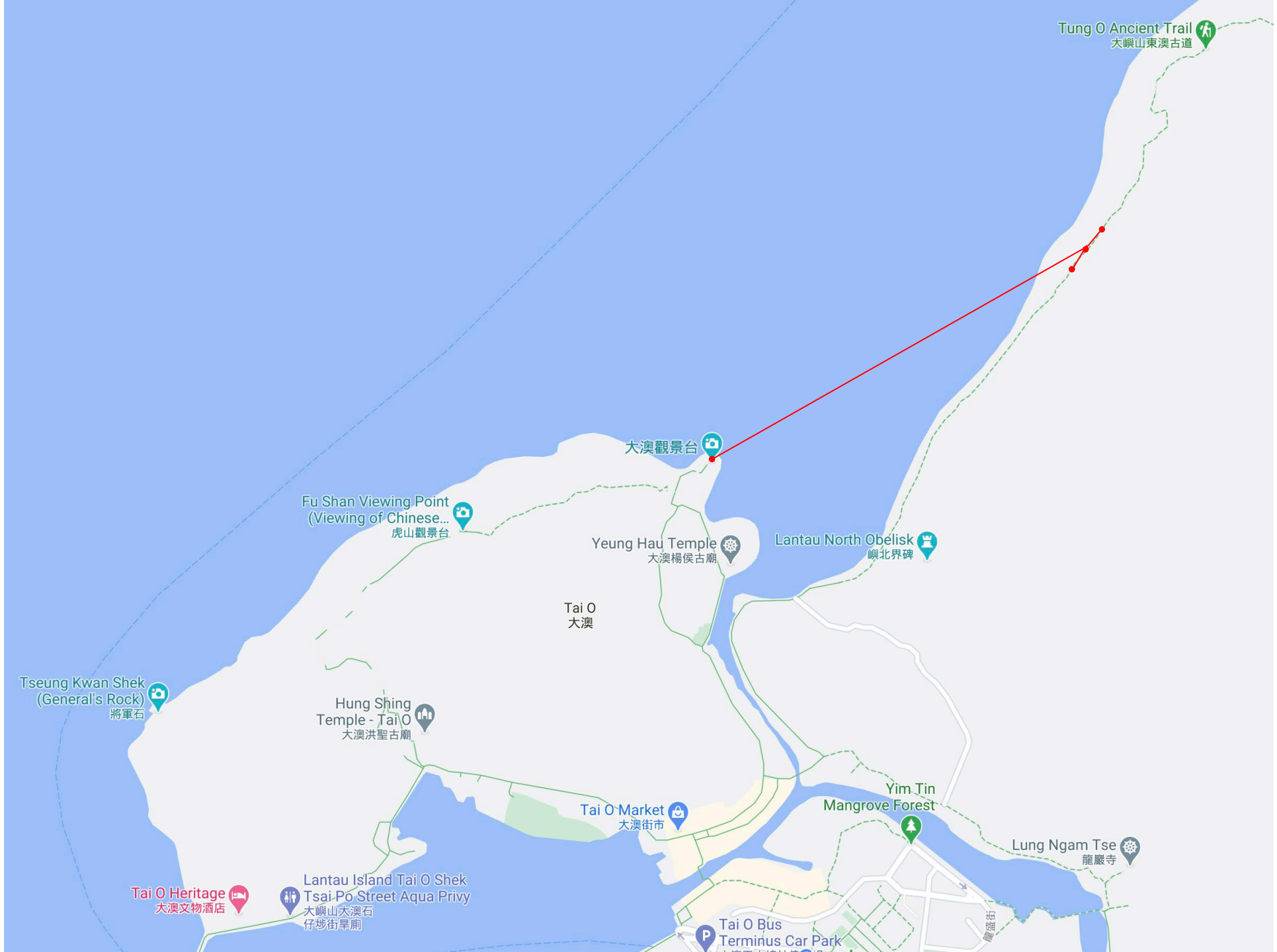
Le Président du Jury: David Tajl

Le Président du Salon: Jean-Luc Vincent

Lantau Country Park Pilot Project

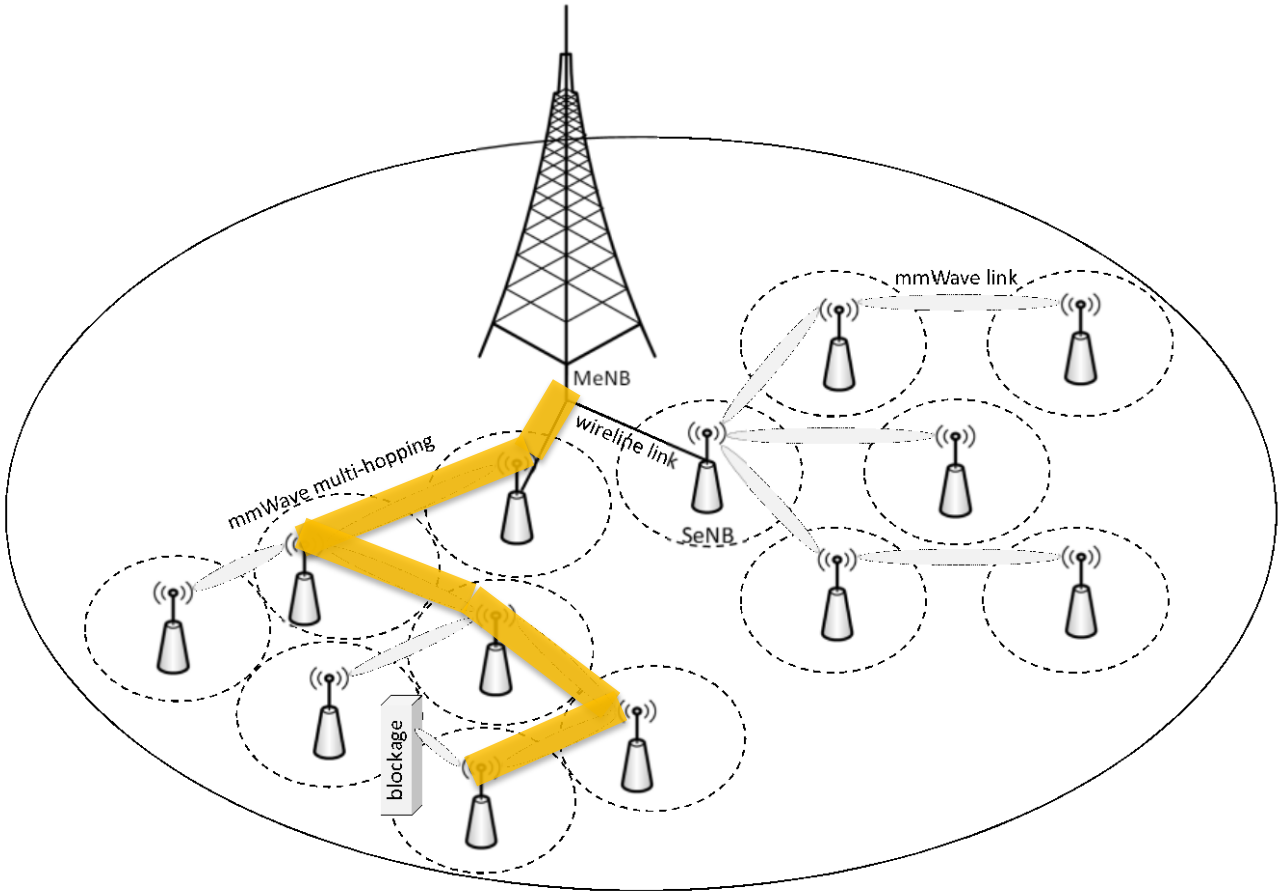
- Most parts of country parks not covered by cellular, incurring threats to hikers
- n-hop has been engaged by CEDD 土木工程拓展處 to use BATS to provide WiFi service for Google maps, WhatsApp, GPS positioning, etc
- Pilot trial: POC at 東澳古道


China Sea
Tung Wan
Ma Wan
馬灣
Hong Kong
Boundary
Crossing
Facilities
港珠澳大橋
香港口岸
人工島
Chek Lap Kok
赤鱲角
HONG KONG
DISNEYLAND
RESORT
香港迪士尼
樂園度假區
DISCOVERY BAY
愉景灣
TUNG CHUNG
東涌
Peng Chau
坪洲
Lantau Island
大嶼山
NGONG PING
昂坪
Lantau South
Country Park
南大嶼
郊野公園
Hei Ling Chau
喜靈洲
Cheung Chau
長洲
Shek Kwu
Chau
石鼓洲
8
9
3


Tung O Ancient Trail
大嶼山東澳古道
大澳觀景台
Fu Shan Viewing Point
(Viewing of Chinese...
虎山觀景台
Yeung Hau Temple
大澳楊侯古廟
Lantau North Obelisk
嶼北界碑
Tai O
大澳
Tseung Kwan Shek
(General's Rock)
將軍石
Hung Shing
Temple - Tai O
大澳洪聖古廟
Tai O Market
大澳街市
Yim Tin
Mangrove Forest
Lung Ngam Tse
龍巖寺
Tai O Heritage
大澳文物酒店
Lantau Island Tai O Shek
Tsai Po Street Aqua Privy
大嶼山大澳石
仔埗街旱廁
Tai O Bus
Terminus Car Park

BATS in 5G

- Integrated Access and Backhaul (IAB)



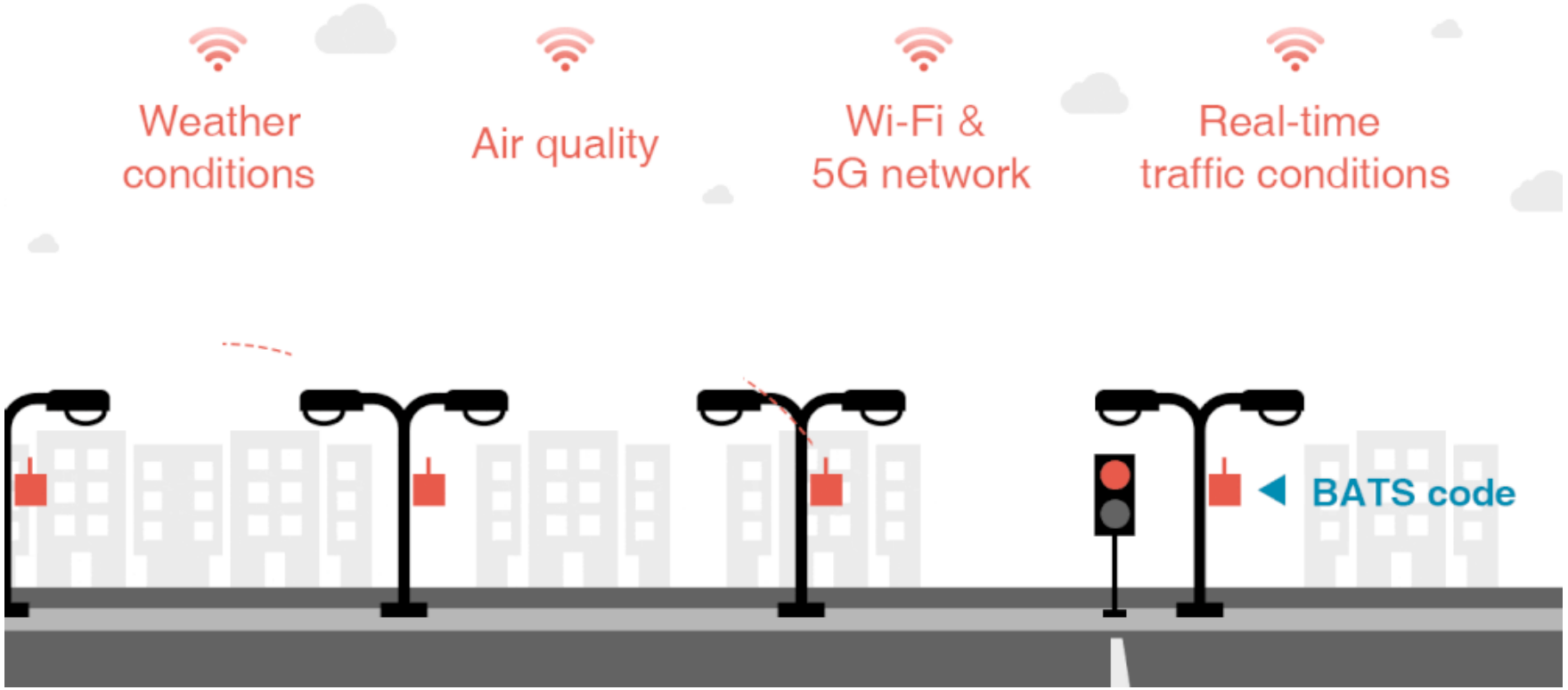
B. P. S. Sahoo, C.-H. Yao, and H.-Y. Wei, “Millimeter-Wave Multi-hop Wireless Backhauling for 5G Cellular Networks,” 2017 VTC-Spring.

- Integrated Access and Backhaul (IAB)
- 5G + BATS = 5G extension
  - Can provide WiFi services to shopping arcades, factories, and other facilities

Conclusion

- BATS is an enabling technology for smart cities infrastructure
- Hong Kong is first city that has BATS deployment
- Two use cases
  - Smart lampposts
  - Country park WiFi coverage
- BATS can expenditure smart cities deployment around the world
- Numerous other potential applications

Thank you


Weather conditions
Air quality
Wi-Fi & 5G network
Real-time traffic conditions
BATS code