
Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Wi-SUN: An IoT network that has been successfully commercialized on a large scale by IEEE 802.15.4]

Date Submitted: 15 January 2025

Source: Hiroshi Harada (Kyoto University/NICT)

Address Yoshidahonmachi. Sakyo, Kyoto, 606-8501, Japan

Voice: +81-75-753-5317 , E-Mail: harada@ieee.org

Re: []

Abstract: The Wireless Smart Utility Network (Wi-SUN) system is an IoT network that has been successfully commercialized on a large scale based on IEEE 802.15.4. This presentation introduces an overview of the Wi-SUN system, its basic characteristics, and future developments. A part of this contribution is supported by National Institute of Information and Communications, Japan Technology (No. JPJ012368C05101) and MIC/Japan (JPJ000254).”

Purpose:

Notice: This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

Release: The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.

Wi-SUN: An IoT network that has been successfully commercialized on a large scale by IEEE 802.15.4

Jan. 15, 2024

Hiroshi Harada, Ph.D., IEEE Fellow

Professor, Kyoto University

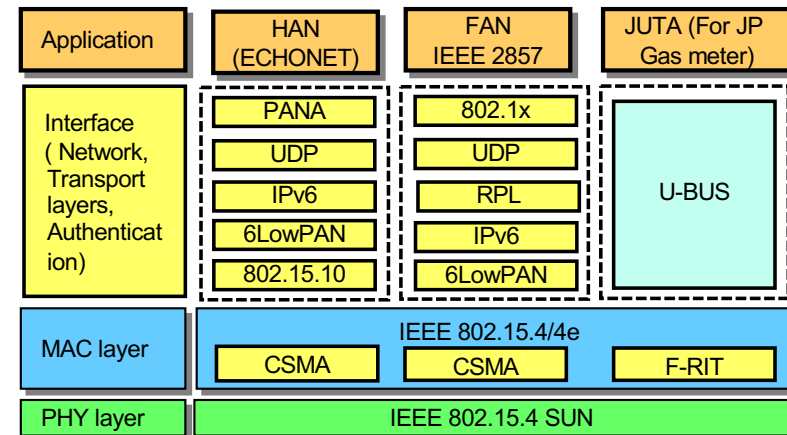
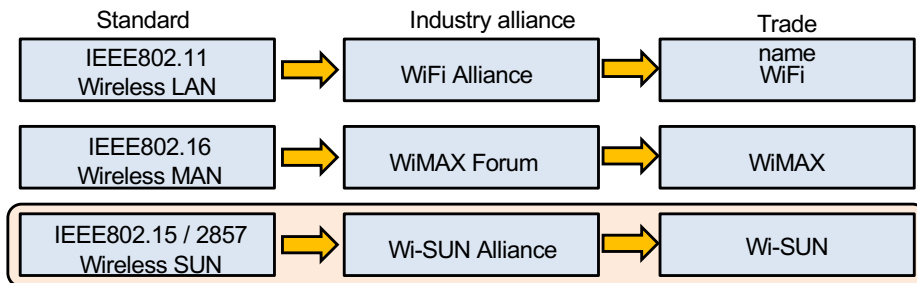
Executive research director, NICT

Chairman of the Board of Directors, Wi-SUN alliance

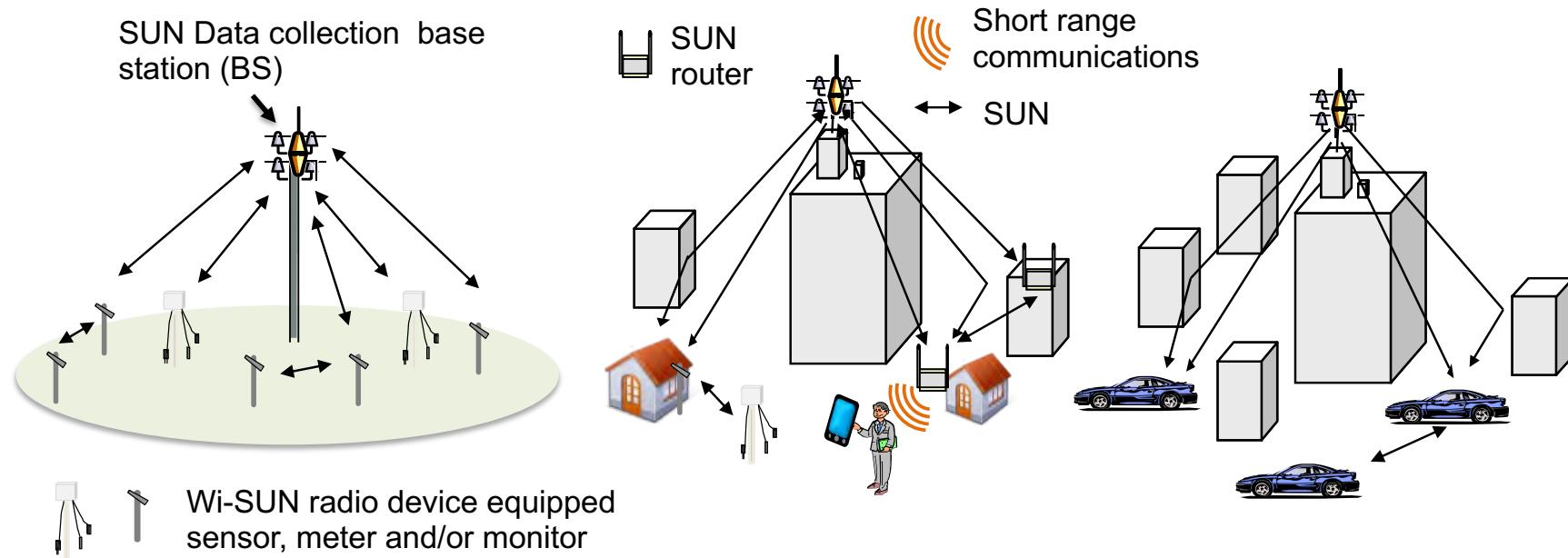
Vice Chair, IEEE 802.15.4g/15.4m/15.4aa/15.4ad and IEEE 2857

Wireless Smart Utility Network (Wi-SUN)

- Definition of SUN (From 802.15.4-2024)
 - Enable multiple applications to operate over shared network resources, providing monitoring and control of a utility system.
 - Devices are designed to operate in very large-scale, low-power wireless applications and often require using the maximum transmit power available under applicable regulations, in order to provide long-range, point-to-point connections.
 - Required to cover geographically widespread areas containing a large number of outdoor devices.
 - Devices typically employ mesh or peer-to-peer multihop techniques to communicate with an access point.
- Mainly used in the smart metering systems but not limited to
 - Smart city, Street factory, V2X, Medical agriculture...
- Wi-SUN alliance, established in 2012, certified IEEE 802.15.4 SUN-based devices worldwide
- Wi-SUN alliance certified three brands of products based on IEEE 802.15.4



Expected use cases



(a) Wide area open space communication

(b) Wide area urban area communication

(c) Wide area mobile communication

H. Harada, K. Mizutani, J. Fujiwara, K. Mochizuki, K. Obata, and R. Okumura, "IEEE 802.15.4g based Wi-SUN Communication Systems," IEICE Transactions on Communications, E100-B, No. 07, pp. 1032-1043, Jul. 2017.

PHY parameters focusing on Wi-SUN

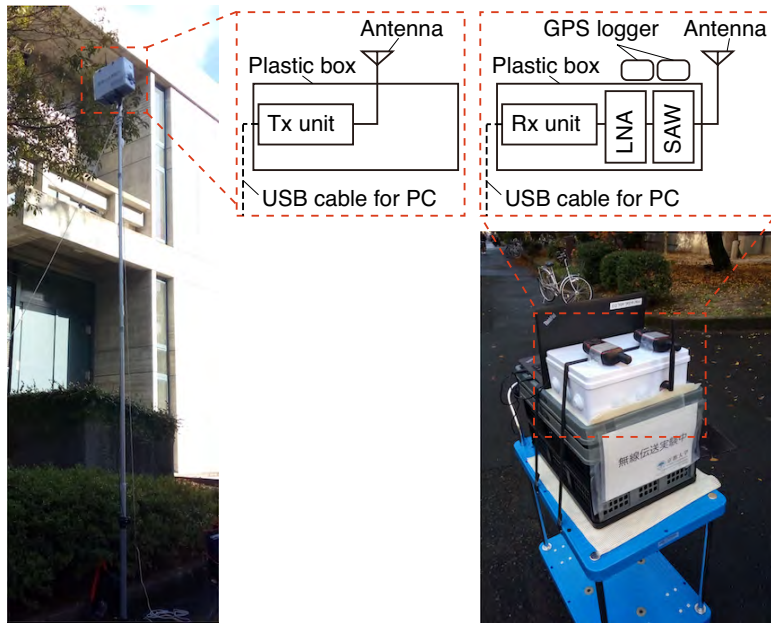
FSK

Parameter	mode #1	mode #2	mode #3	mode #6	mode #7	mode #8	mode #9	mode #10
Data rate (kb/s)	50	100	200	150	300	300	400	600
Modulation	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK	2-FSK
Modulation index	1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.4
Channel spacing (KHz)	200	400	600	400	400	600	1000	1000

OFDM

	Option1	Option2	Option3	Option4	
Nominal Bandwidth	1094 kHz	552 kHz	281 kHz	156 kHz	
Channel spacing	1200 kHz	800 kHz	400 kHz	200 kHz	
Subcarrier spacing	31.25/3 kHz				
DFT size	128	64	32	16	
Primary modulation scheme	BPSK(MCS 0-1), QPSK(MCS 2-4), 16QAM(MCS5-6)				
Coding Scheme and rate	Convolutional code (Constraint length: 7) Coding rate 1/2 (MCS 0-3, 5), 3/4 (MCS 4,6)				
Spreading factor	4 (MCS 0), 2 (MCS1-2), 1(MCS 3-6)				
Data rate for PSDU (kb/s)	MCS 0	100	50	25	12.5
	MCS 1	200	100	50	25
	MCS 2	400	200	100	50
	MCS 3	800	400	200	100
	MCS 4	1200	600	300	150
	MCS 5	1600	800	400	200

Field Experiment with FSK

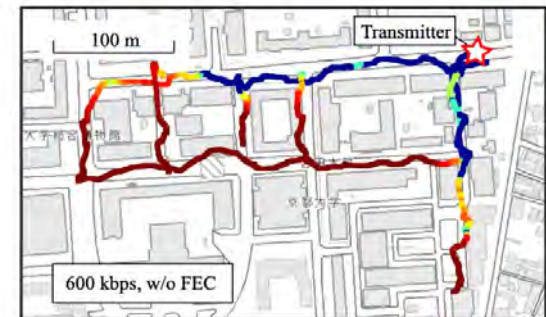
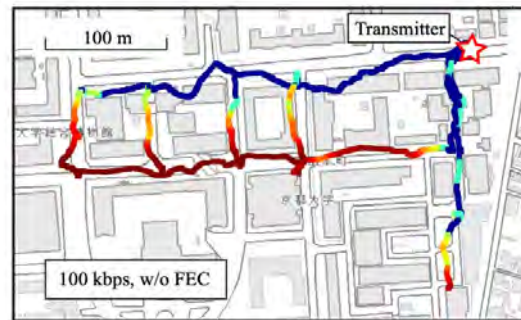
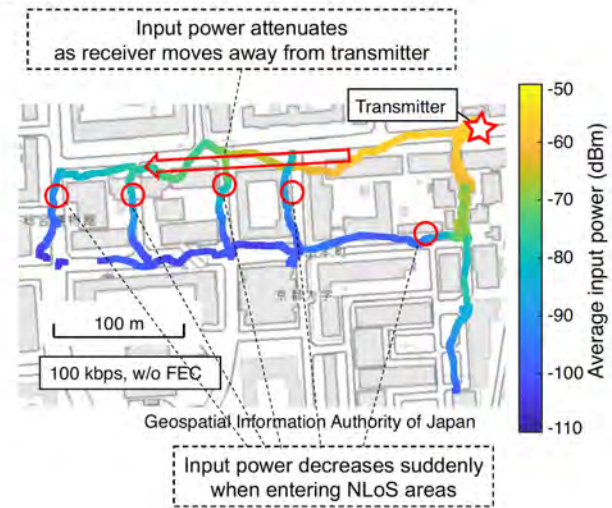


(a) Transmitter setup

(b) Receiver setup

Antenna height: 4.5 m
 Transmission power: 20mW
 IEEE 802.15.4-SUN FSK

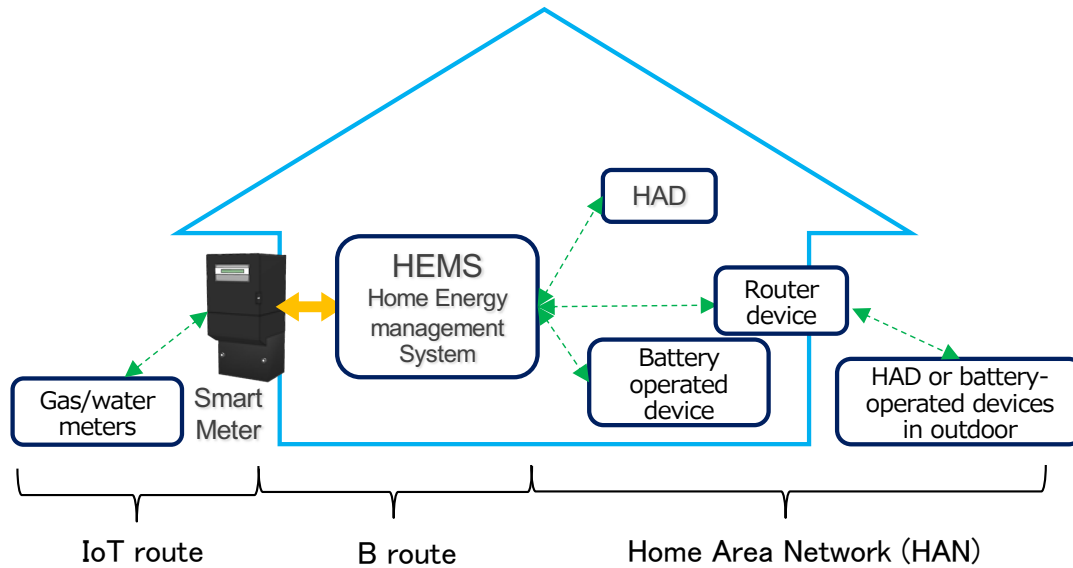
Antenna height: 1.1 m



Y. Xiang, R. Okumura, K. Mizutani, and H. Harada, "Data Rate Enhancement of FSK Transmission Scheme for IEEE 802.15. 4-Based Field Area Network," IEEE Sensors Journal, Vol. 21, no.7, Jan. 2021

Main applications of Wi-SUN system

Home Area Network (HAN)



Application layer	ECHONET Lite
Access authentication	PANA (authentication + Share encryption key)
Transport layer	UDP
Network layer	IPv6, ICMPv6
Adaptation layer	6LoWPAN
Datalink layer (MAC layer)	IEEE 802.15.10 Relay IEEE 802.15.4/4e
Physical layer	IEEE 802.15.4-2015 (920MHz, FSK, 100 kbps)

■ **Standardized by Wi-SUN HAN and TTC JJ.300.10**

- B-route
 - Communication between smart meter and HEMS
 - Wi-SUN HAN (B-route) supported
- HAN(Home Area Network)
 - Communication between HEMS, home appliance devices, and battery-operated devices
 - One-hop relay is possible using a relay device.
- IoT route
 - Realize joint metering of electricity, gas, and water
 - Wi-SUN enhanced HAN supported

1st Generation smart meter installation plan in Japan

All JP power companies need to adopt Wi-SUN B-route when installing smart meters (over100 millions)

Region	Primary Technology	Secondary Technology
Hokkaido	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Tohoku	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Tokyo	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Chubu	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Hokuriku	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Kansai	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Chugoku	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Shikoku	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Kyushu	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)
Okinawa	920MHz Wireless (Wi-SUN IP system)	PLC (G3 PLC System)

Utility providers have chosen the primary technology as the main approach, with secondary technology in consideration if the deployment is challenging for the former

Source: METI Smart Metering Report - http://www.meti.go.jp/committee/summary/0004668/pdf/015_03_00.pdf

1st Generation smart meter installation plan in Japan

Region	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Hokkaido		380	530	480	490	510	510	520	560	570	
Tohoku	120	650	840	820	810	800	780	730	730	720	
Tokyo	1900	3200	5700	5700	5700	3300	3300				
Chubu	10	1020	1460	1440	1420	1390	1390	1420	1390		
Hokuriku		150	250	250	230	230	220	190	190	160	
Kansai	1600	1700	1700	1700	1500	1300	1300	1200	1100		
Chugoku		240	560	610	610	610	610	610	610	610	
Shikoku	30	150	310	310	310	310	310	310	310	300	
Kyushu			800	850	850	1090	1010	1000	890	790	
Okinawa		10	100	100	100	100	100	100	90	90	90

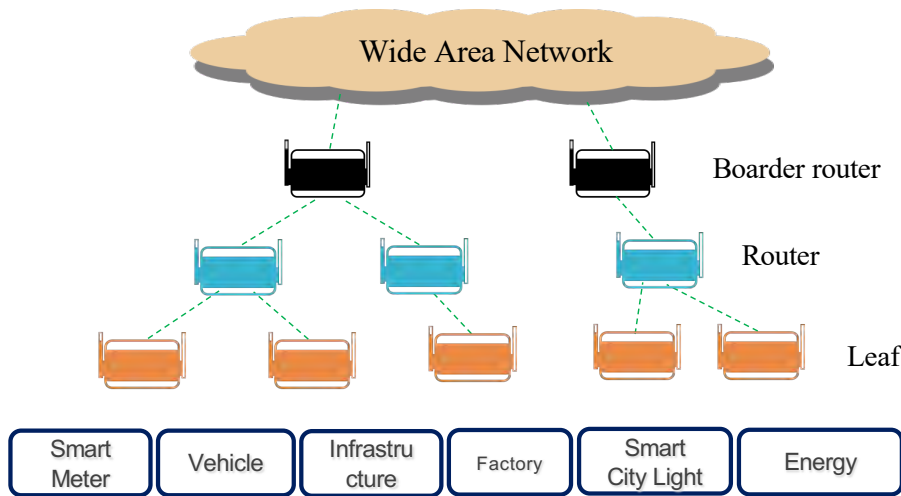
In units of 1000

Total number of smart meters to be deployed by end of 2020 expected to reach **66.86 million**

Source: METI Smart Metering Report - http://www.meti.go.jp/committee/summary/0004668/pdf/015_03_00.pdf

Main applications of Wi-SUN system

Field Area Network (FAN)



- Border router (BR)
 - Wide Area Network (WAN) connectivity
 - Source routing table for all nodes within its Personal Area Network (PAN)
- Router
 - Upward and downward packet forwarding
 - Send and receive packets
- Leaf node
 - No child nodes connected
 - Only sending/Receiving packets

Application layer	Up to vendors or providers
Access authentication	IEEE 802.1X
Transport layer	UDP/TCP(option)
Network layer	Multihop: RPL IPv6, ICMPv6
Adaptation layer	6LoWPAN
Datalink layer (MAC layer)	IEEE 802.15.4/4e
Physical layer	IEEE 802.15.4-2015 FAN1.0: FSK FAN1.1: FSK and OFDM

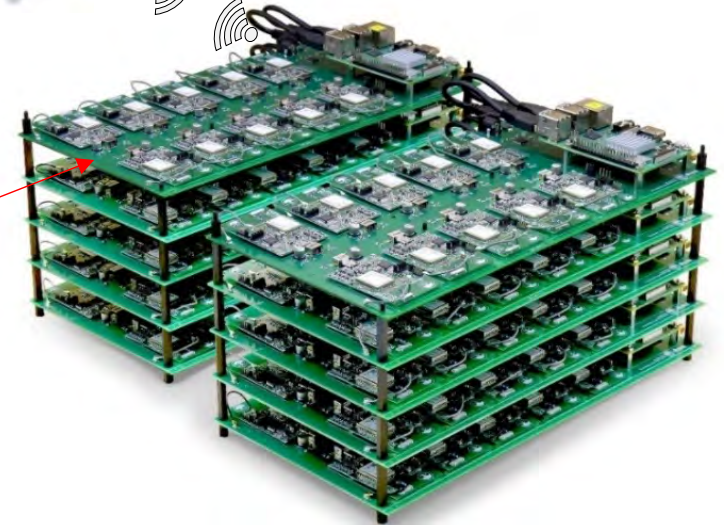
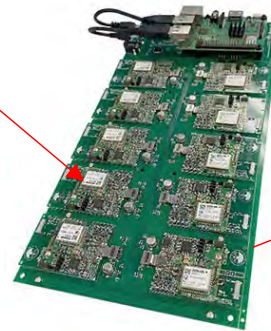
- **Standardized by IEEE 2857 and Wi-SUN FAN 1.0**
- Expansion of communication area through multi-hop with over 20 hops
- Even if devices are installed in close proximity to each other, interference between devices is avoided by frequency hopping.

Development of Wi-SUN FAN

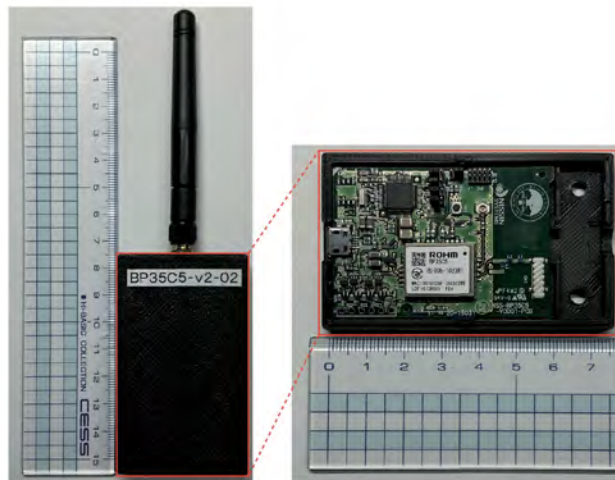


Wi-SUN FAN board (version 1.0 FSK-based)

Boarder router



Wi-SUN FAN large scale evaluation system



Wi-SUN FAN radio unit

Wi-SUN FAN large scale evaluation with 500 units



200-00001	200-00002	200-00003	200-00004	200-00005	200-00006	200-00007	200-00008	200-00009	200-00010
200-00011	200-00012	200-00013	200-00014	200-00015	200-00016	200-00017	200-00018	200-00019	200-00020
200-00021	200-00022	200-00023	200-00024	200-00025	200-00026	200-00027	200-00028	200-00029	200-00030
200-00031	200-00032	200-00033	200-00034	200-00035	200-00036	200-00037	200-00038	200-00039	200-00040
200-00041	200-00042	200-00043	200-00044	200-00045	200-00046	200-00047	200-00048	200-00049	200-00050
200-00051	200-00052	200-00053	200-00054	200-00055	200-00056	200-00057	200-00058	200-00059	200-00060
200-00061	200-00062	200-00063	200-00064	200-00065	200-00066	200-00067	200-00068	200-00069	200-00070
200-00071	200-00072	200-00073	200-00074	200-00075	200-00076	200-00077	200-00078	200-00079	200-00080
200-00081	200-00082	200-00083	200-00084	200-00085	200-00086	200-00087	200-00088	200-00089	200-00090
200-00091	200-00092	200-00093	200-00094	200-00095	200-00096	200-00097	200-00098	200-00099	200-00100
200-00101	200-00102	200-00103	200-00104	200-00105	200-00106	200-00107	200-00108	200-00109	200-00110
200-00111	200-00112	200-00113	200-00114	200-00115	200-00116	200-00117	200-00118	200-00119	200-00120
200-00121	200-00122	200-00123	200-00124	200-00125	200-00126	200-00127	200-00128	200-00129	200-00130
200-00131	200-00132	200-00133	200-00134	200-00135	200-00136	200-00137	200-00138	200-00139	200-00140
200-00141	200-00142	200-00143	200-00144	200-00145	200-00146	200-00147	200-00148	200-00149	200-00150
200-00151	200-00152	200-00153	200-00154	200-00155	200-00156	200-00157	200-00158	200-00159	200-00160
200-00161	200-00162	200-00163	200-00164	200-00165	200-00166	200-00167	200-00168	200-00169	200-00170
200-00171	200-00172	200-00173	200-00174	200-00175	200-00176	200-00177	200-00178	200-00179	200-00180
200-00181	200-00182	200-00183	200-00184	200-00185	200-00186	200-00187	200-00188	200-00189	200-00190
200-00191	200-00192	200-00193	200-00194	200-00195	200-00196	200-00197	200-00198	200-00199	200-00200
200-00201	200-00202	200-00203	200-00204	200-00205	200-00206	200-00207	200-00208	200-00209	200-00210
200-00211	200-00212	200-00213	200-00214	200-00215	200-00216	200-00217	200-00218	200-00219	200-00220
200-00221	200-00222	200-00223	200-00224	200-00225	200-00226	200-00227	200-00228	200-00229	200-00230
200-00231	200-00232	200-00233	200-00234	200-00235	200-00236	200-00237	200-00238	200-00239	200-00240
200-00241	200-00242	200-00243	200-00244	200-00245	200-00246	200-00247	200-00248	200-00249	200-00250
200-00251	200-00252	200-00253	200-00254	200-00255	200-00256	200-00257	200-00258	200-00259	200-00260
200-00261	200-00262	200-00263	200-00264	200-00265	200-00266	200-00267	200-00268	200-00269	200-00270
200-00271	200-00272	200-00273	200-00274	200-00275	200-00276	200-00277	200-00278	200-00279	200-00280
200-00281	200-00282	200-00283	200-00284	200-00285	200-00286	200-00287	200-00288	200-00289	200-00290
200-00291	200-00292	200-00293	200-00294	200-00295	200-00296	200-00297	200-00298	200-00299	200-00300
200-00301	200-00302	200-00303	200-00304	200-00305	200-00306	200-00307	200-00308	200-00309	200-00310
200-00311	200-00312	200-00313	200-00314	200-00315	200-00316	200-00317	200-00318	200-00319	200-00320
200-00321	200-00322	200-00323	200-00324	200-00325	200-00326	200-00327	200-00328	200-00329	200-00330
200-00331	200-00332	200-00333	200-00334	200-00335	200-00336	200-00337	200-00338	200-00339	200-00340
200-00341	200-00342	200-00343	200-00344	200-00345	200-00346	200-00347	200-00348	200-00349	200-00350
200-00351	200-00352	200-00353	200-00354	200-00355	200-00356	200-00357	200-00358	200-00359	200-00360
200-00361	200-00362	200-00363	200-00364	200-00365	200-00366	200-00367	200-00368	200-00369	200-00370
200-00371	200-00372	200-00373	200-00374	200-00375	200-00376	200-00377	200-00378	200-00379	200-00380
200-00381	200-00382	200-00383	200-00384	200-00385	200-00386	200-00387	200-00388	200-00389	200-00390
200-00391	200-00392	200-00393	200-00394	200-00395	200-00396	200-00397	200-00398	200-00399	200-00400
200-00401	200-00402	200-00403	200-00404	200-00405	200-00406	200-00407	200-00408	200-00409	200-00410
200-00411	200-00412	200-00413	200-00414	200-00415	200-00416	200-00417	200-00418	200-00419	200-00420
200-00421	200-00422	200-00423	200-00424	200-00425	200-00426	200-00427	200-00428	200-00429	200-00430
200-00431	200-00432	200-00433	200-00434	200-00435	200-00436	200-00437	200-00438	200-00439	200-00440
200-00441	200-00442	200-00443	200-00444	200-00445	200-00446	200-00447	200-00448	200-00449	200-00450
200-00451	200-00452	200-00453	200-00454	200-00455	200-00456	200-00457	200-00458	200-00459	200-00460
200-00461	200-00462	200-00463	200-00464	200-00465	200-00466	200-00467	200-00468	200-00469	200-00470
200-00471	200-00472	200-00473	200-00474	200-00475	200-00476	200-00477	200-00478	200-00479	200-00480
200-00481	200-00482	200-00483	200-00484	200-00485	200-00486	200-00487	200-00488	200-00489	200-00490
200-00491	200-00492	200-00493	200-00494	200-00495	200-00496	200-00497	200-00498	200-00499	200-00500

Press release by Kyoto Univ. and Nissin systems, Nov. 15, 2021

Demonstration

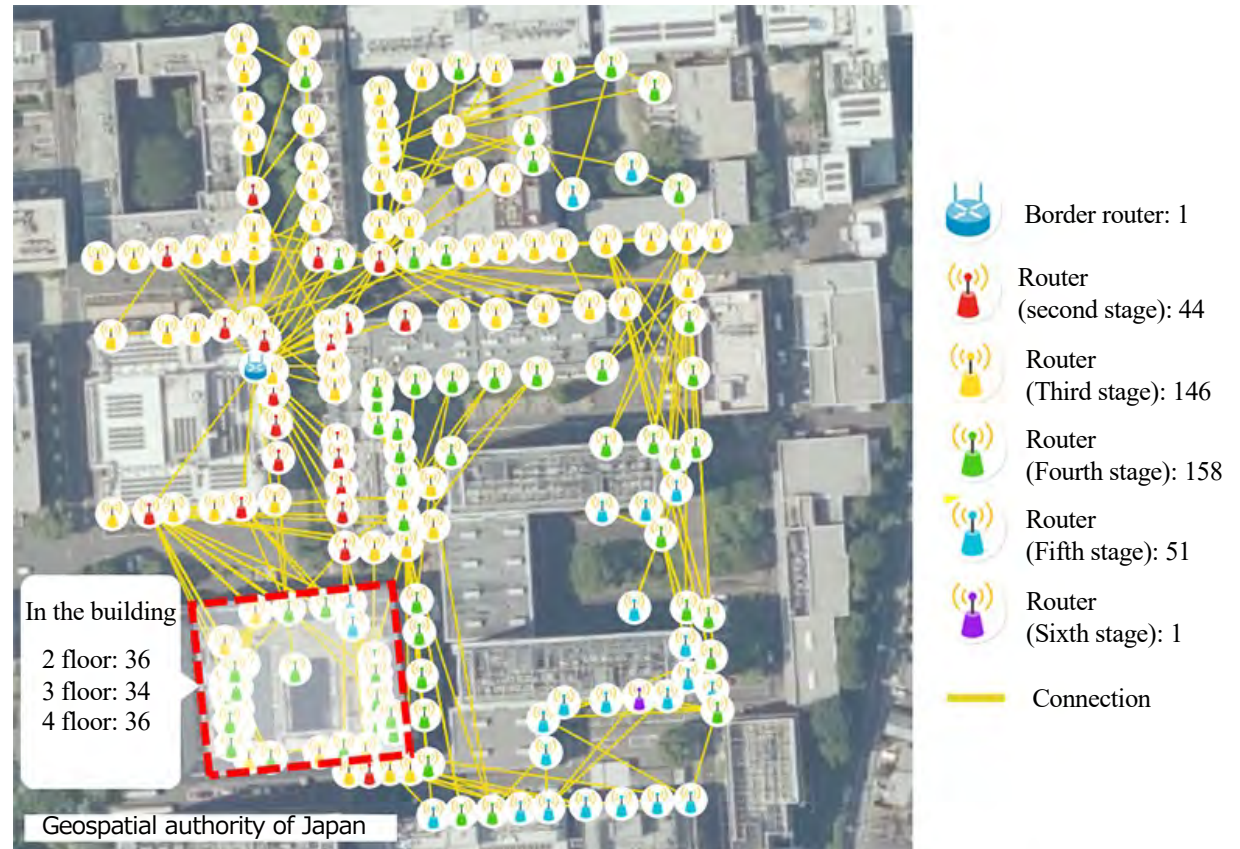


Wi-SUN FAN large-scale field trial with 400 units

- 400 Wi-SUN FAN devices with mobile battery randomly placed in the field
- Continuous operation over several days
- Communication success rate of 97.1% or higher established

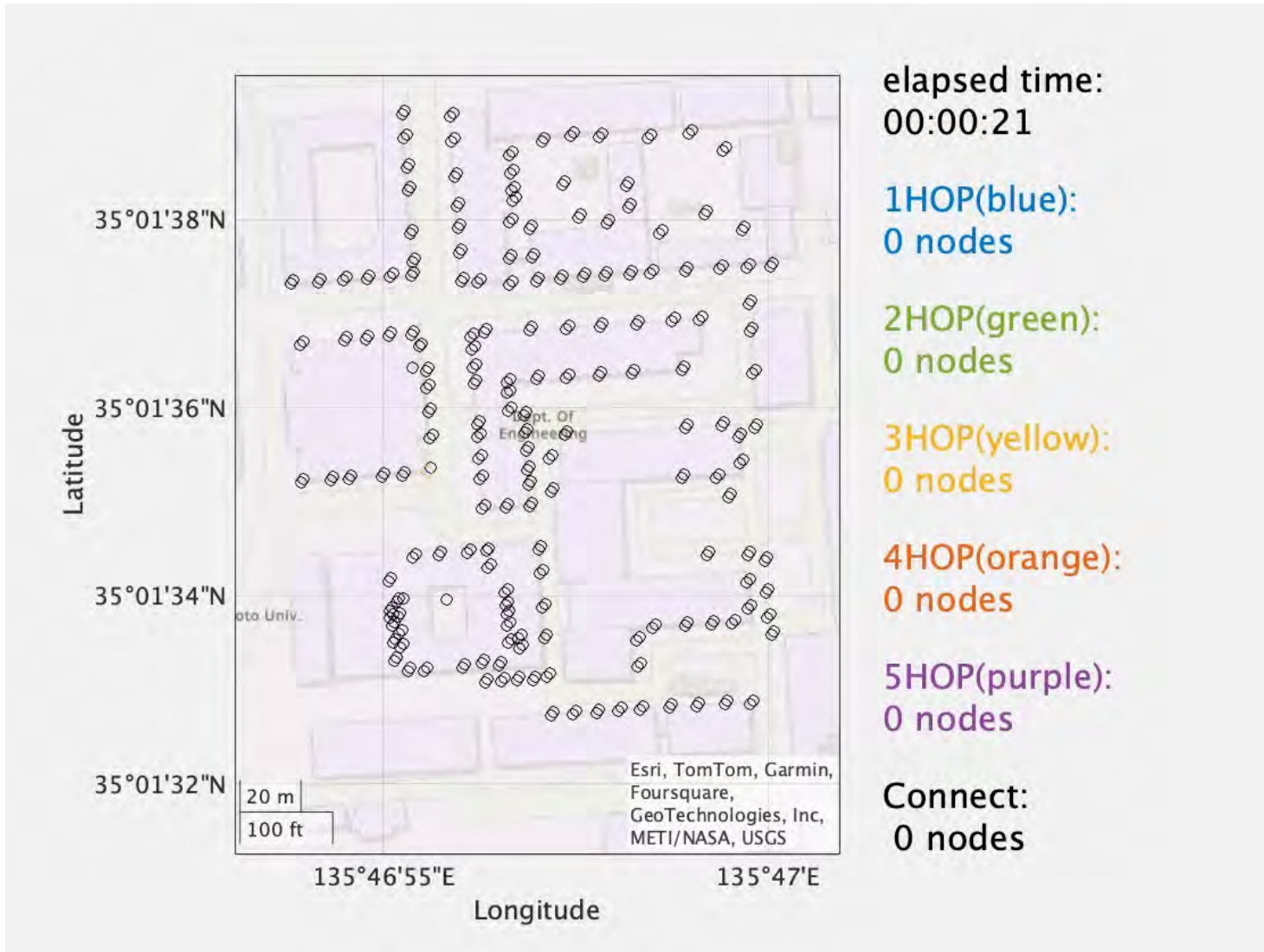


Wi-SUN radio device



Press release by Kyoto Univ. and Nissin systems, March 30, 2023

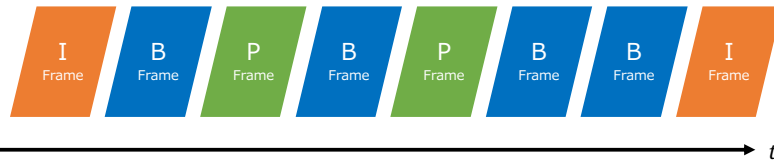
Demonstration with Wi-SUN FAN 400 nodes



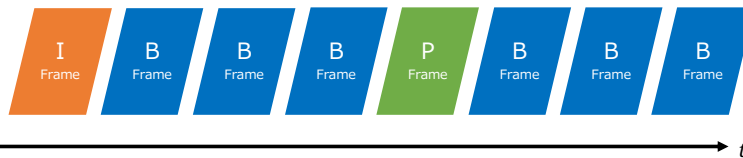
Wi-SUN FAN Next step: Video transmission

- A New Video transmission method is used [1]
 - ◆ According to the amount of image change between the frames, the I-frames are changed to P-frames and B-frames, and P-frames are changed to B-frames

Conventional method



Proposed method

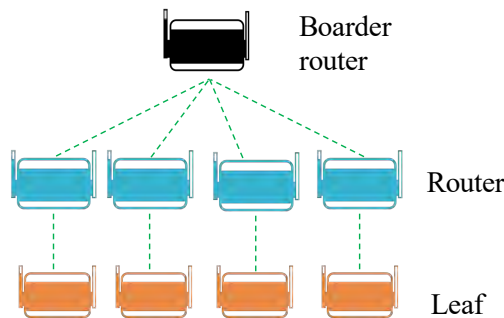
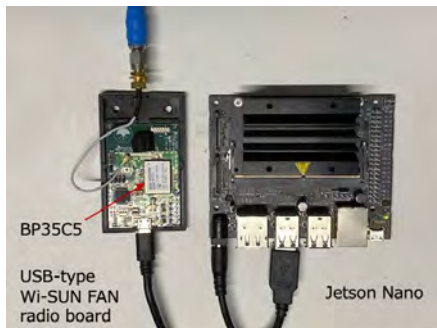


Leaf 1: 1280 × 720
 Frame rate : 5 fps
 Bit rate : 100 kbps

Leaf 2: 640 × 360
 Frame rate : 5 fps
 Bit rate : 50 kbps

Leaf 3: 640 × 360
 Frame rate : 5 fps
 Bit rate : 50 kbps

Leaf 4: 640 × 360
 Frame rate : 5 fps
 Bit rate : 50 kbps



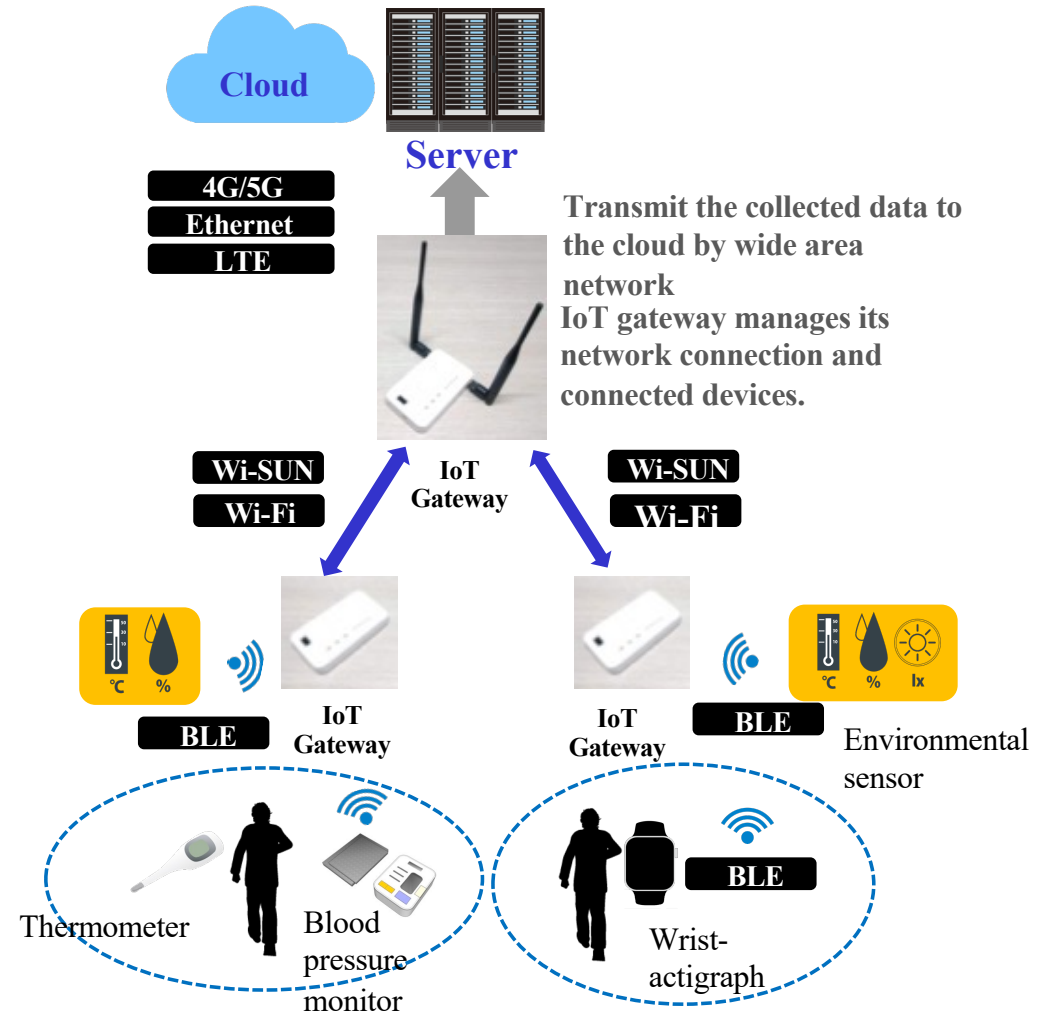
Video source: NASA Image and Video Library. “The-Earth-4K-Extended-Edition MP4”.
https://images.nasa.gov/details-The-Earth-4K-Extended-Edition_MP4

[1] Reo Gakumi, Hiroko Masaki, Keiichi Mizutani, and Hiroshi Harada, “Video Transmission Trial by Wireless Multi-hop Network based on Wi-SUN FAN,” Proc. WPMC 2022, Nov. 2022.

Wi-SUN FAN Next step: Wi-SUN router

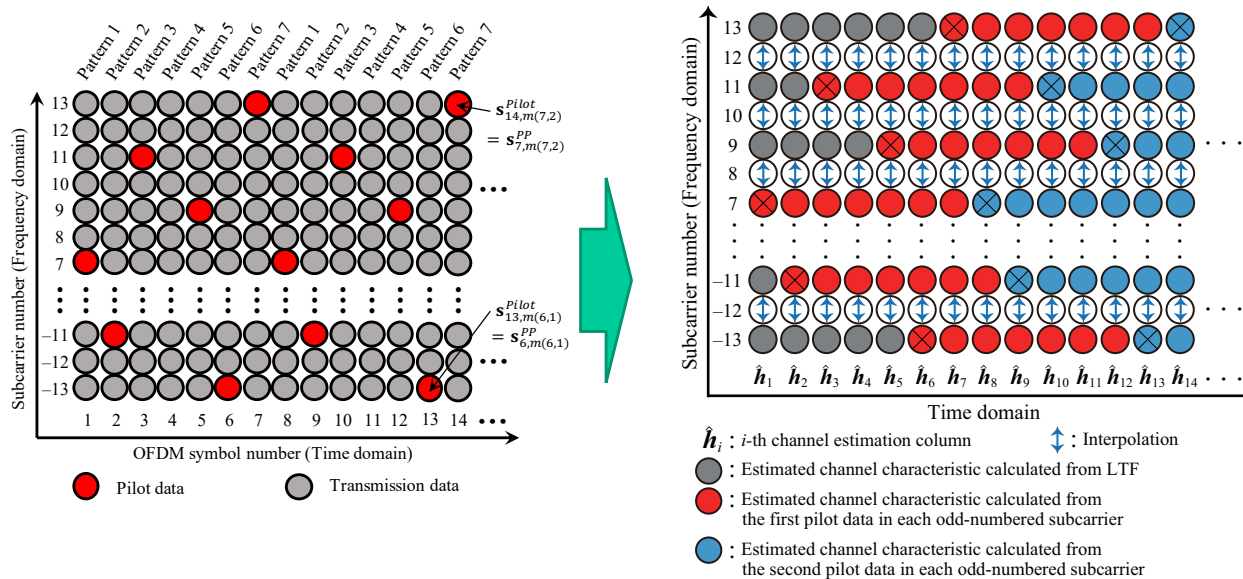


- Equipped with Wi-SUN FAN 1.0 certified by the Wi-SUN Alliance
 - Support 300 kbps FSK
 - Allows selection of internal or external antenna
 - Achieves high communication quality through Wi-SUN antenna diversity
- Equipped with Wi-Fi (Dual-Band 802.11 ac/a/b/g/n) and Bluetooth 5
- Supports power supply via USB Type-C and power supply via JST 2-pin connector (optional)

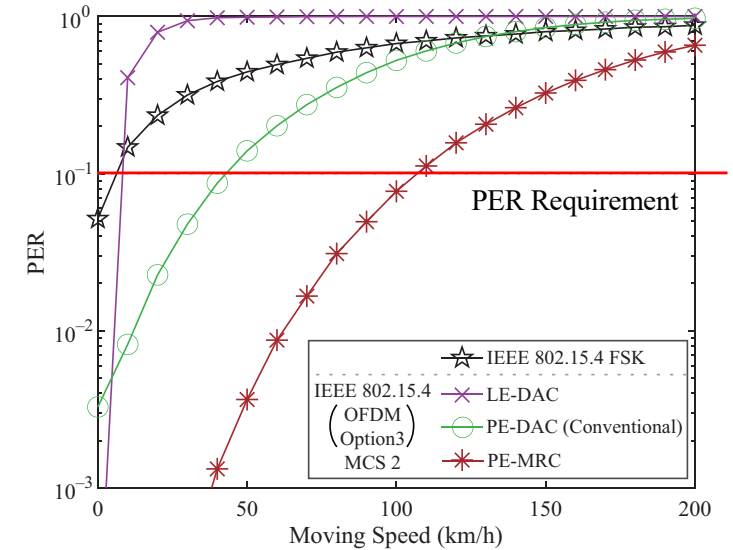


Wi-SUN FAN Next step: V2X communication

Improvement of channel estimation scheme



Wi-SUN at 100km/h is possible



	Parameter	Value
Common	PSDU length	250 octets
	Oversampling	16
	SNR (AWGN level)	37.8 dB
	Channel model	GSM Typical Urban
	Carrier frequency	920 MHz
	Moving speed	0-200 km/h
SUN-FSK	Modulation scheme	2-GFSK
	Preamble length	15 octets
	Data rate	100 kbps
	Modulation index	1.0
	Gaussian filter BT	Tx: 0.5, Rx: 0.5
SUN-OFDM	Encoding scheme	w/o FEC
	Decoding scheme	Viterbi (Soft decision)

Receive scheme	Channel estimation scheme	Diversity in Frequency domain
LE-DAC	LTF only	EGC
PE-DAC	Proposed scheme 1	EGC
PE-MRC	Proposed scheme 1	MRC
ePE-MRC	Proposed scheme 2	MRC

H. Ochiai, Y. Morikawa, K. Mizutani, H. Harada, "An Enhanced Channel Estimation for IEEE 802.15. 4 OFDM Receiver in High-speed Mobile IoT Communication Systems", IEEE Internet of Things Journal, Feb. 2023.

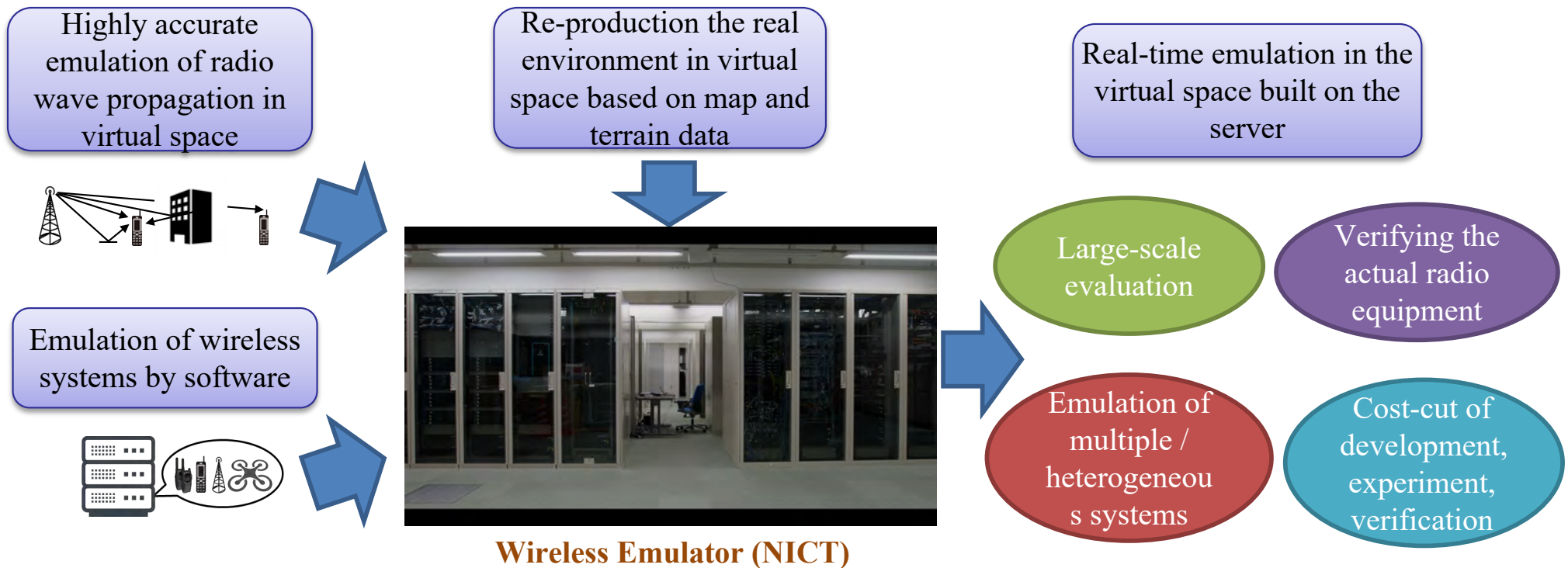
Next Step ... 802.15ad

Large-scale Wi-SUN system emulation using a virtual space and digital twin with a wireless emulator

Wireless emulator

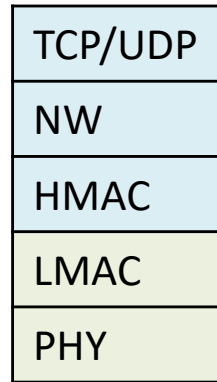
Difficult to evaluate the transmission performance of the wireless communication systems using the actual radio devices in the physical space of the B5G era.

- ❑ When a large-scale wireless system with numerous wireless devices is examined in the future, **it becomes severely difficult to verify transmission characteristics using actual wireless devices.**
- ❑ When the verification of the large-scale system is performed **outdoors**, it becomes **difficult to secure a place** where many of these radio devices are installed; in addition, **the installation cost also increases**



Wireless Smart Utility Network (Wi-SUN)

Wi-SUN device



Current Wi-SUN device



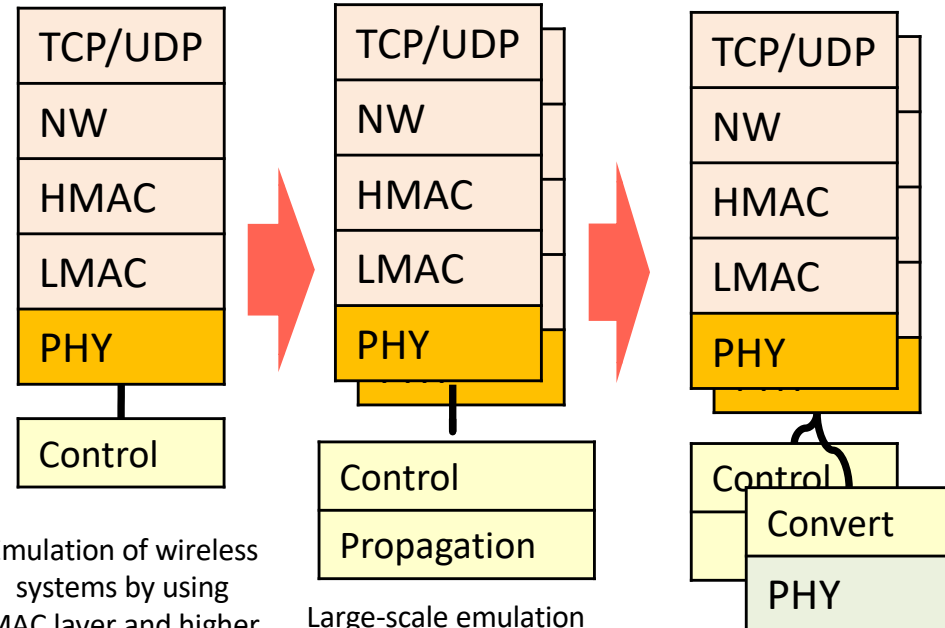
Large-scale evaluation is performed by running the software installed on the actual device on wireless emulators as they are.



Install a large number of terminals in a virtual space, evaluate their transmission characteristics, and, install the modified parts on actual devices based on the results of the evaluation.

- : Signal processing by hardware
- : Signal processing by software on embedded OS

Wi-SUN virtual radio in wireless emulator



Emulation of wireless systems by using MAC layer and higher protocol stacks



Large-scale emulation including terrain data and propagation simulation

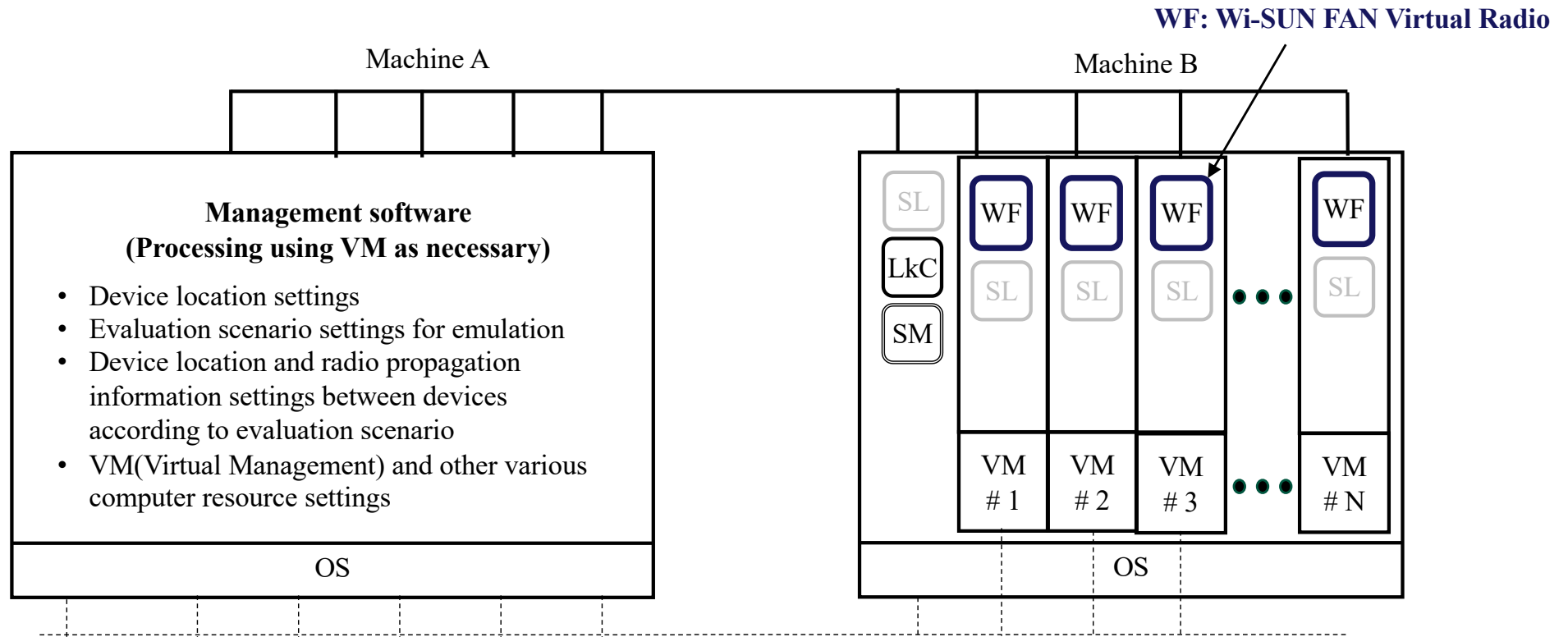


Wireless emulator collaborated with actual radio devices



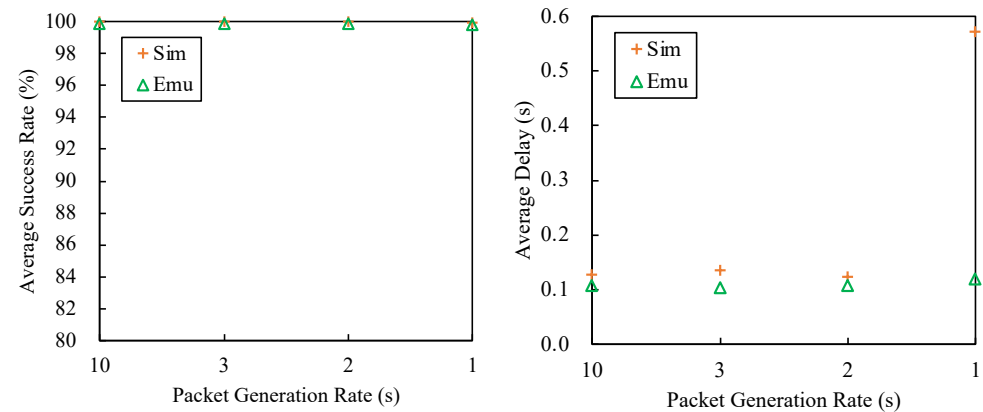
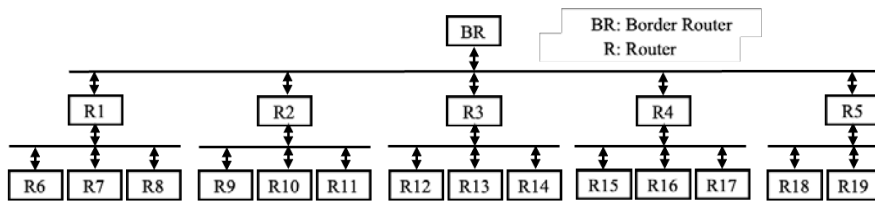
- : Signal processing by software on OS used in wireless emulator (ex. Linux)
- : Emulation by using virtualization on computers

Setup of Wi-SUN virtual radio to emulator



Calibration of wireless emulator

- Tree topology: 20 nodes (1 BR, 5 router, and 14 Leaf Routers)

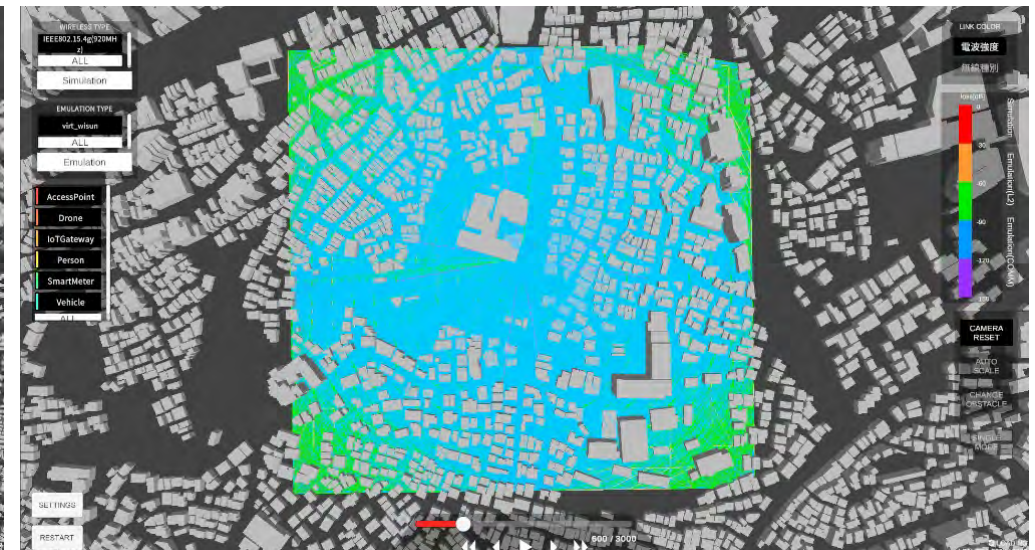
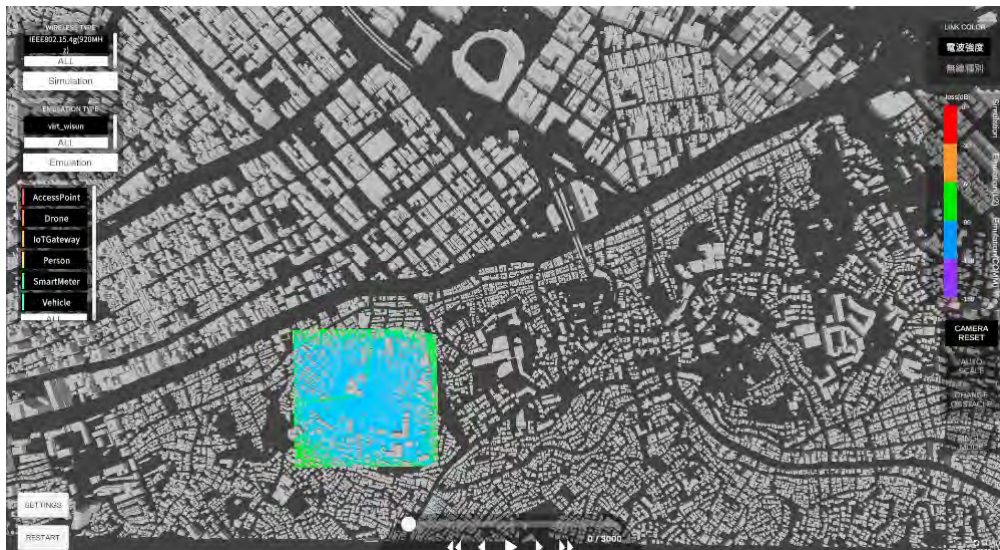


- This figure agrees with the computer simulation results programmed by [1] for validation.
- The average packet reception success rate and average transmission delay time essentially agree well with computer simulation results.
- Compared with star topologies, emulation delays are less than simulations because CSMA/CA determines the collisions in the emulation process

Parameters	Values
Data rate (kbps)	150
Number of frequency hopping channels	14
DAO sending interval (s)	600
Number of data packets	100
Data packets size (byte)	200
Data packets generation rate (s)	1, 2, 3, 10

[1] R. Hirakawa, R. Okumura, K. Mizutani, and H. Harada, "A Novel routing Method with Load-Balancing in Wi-SUN FAN Network," in Proc. WF-IoT 2021, June. 2021.

Emulation of Wi-SUN systems by wireless emulator



1. Installation of wireless virtual devices

(using 3D topographical data)

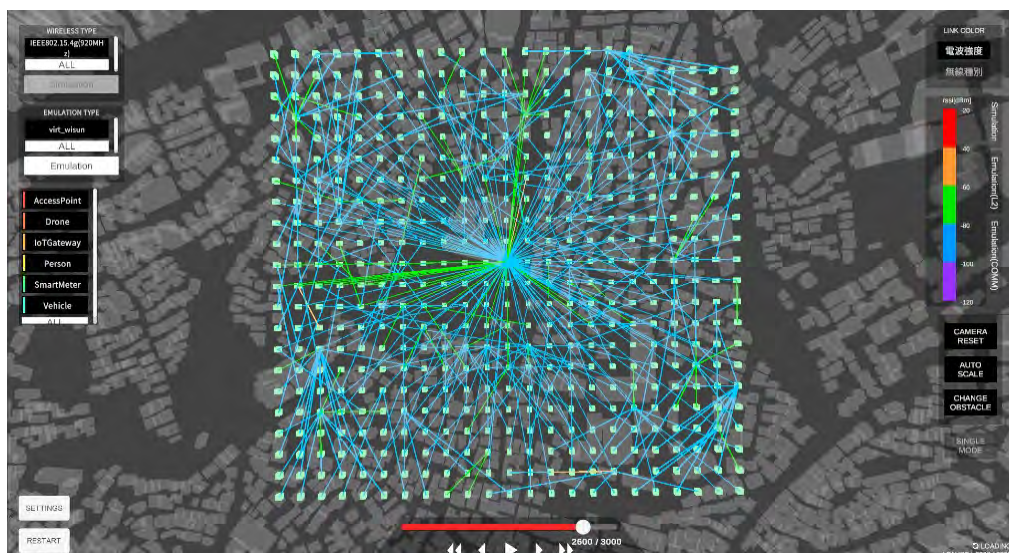
(500 Wi-SUN FAN systems installed in a residential area of Yokohama)

2. Calculate the transmission characteristics of all links

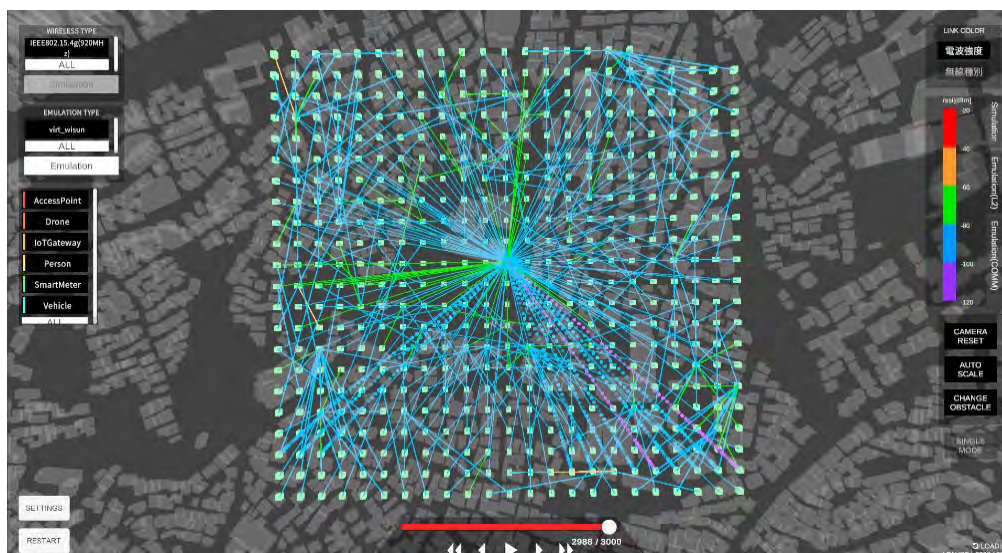
(using 3D topographical data)

(e.g. two waves of ground reflection + shadowing)

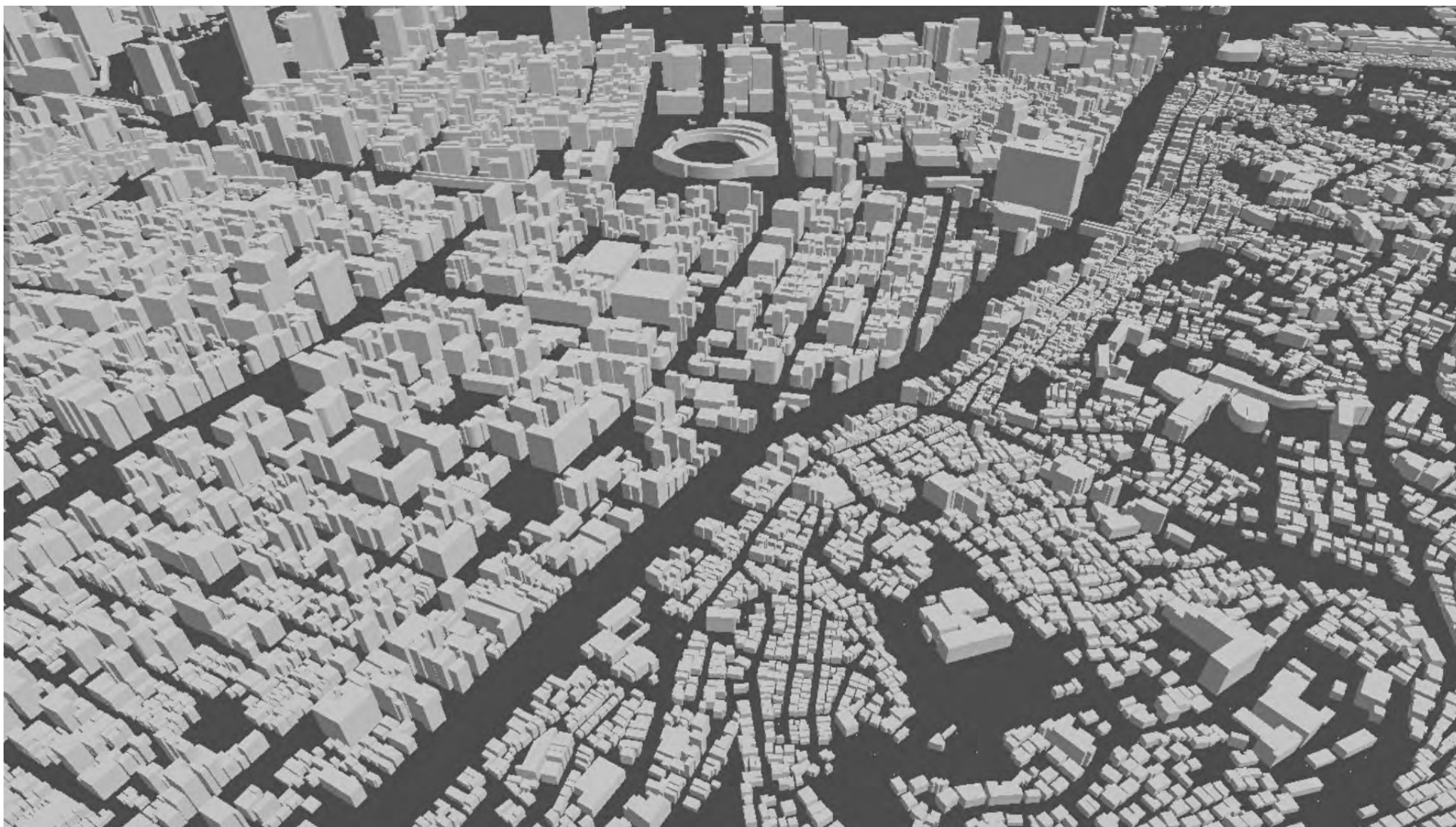
Emulation of Wi-SUN systems by wireless emulator



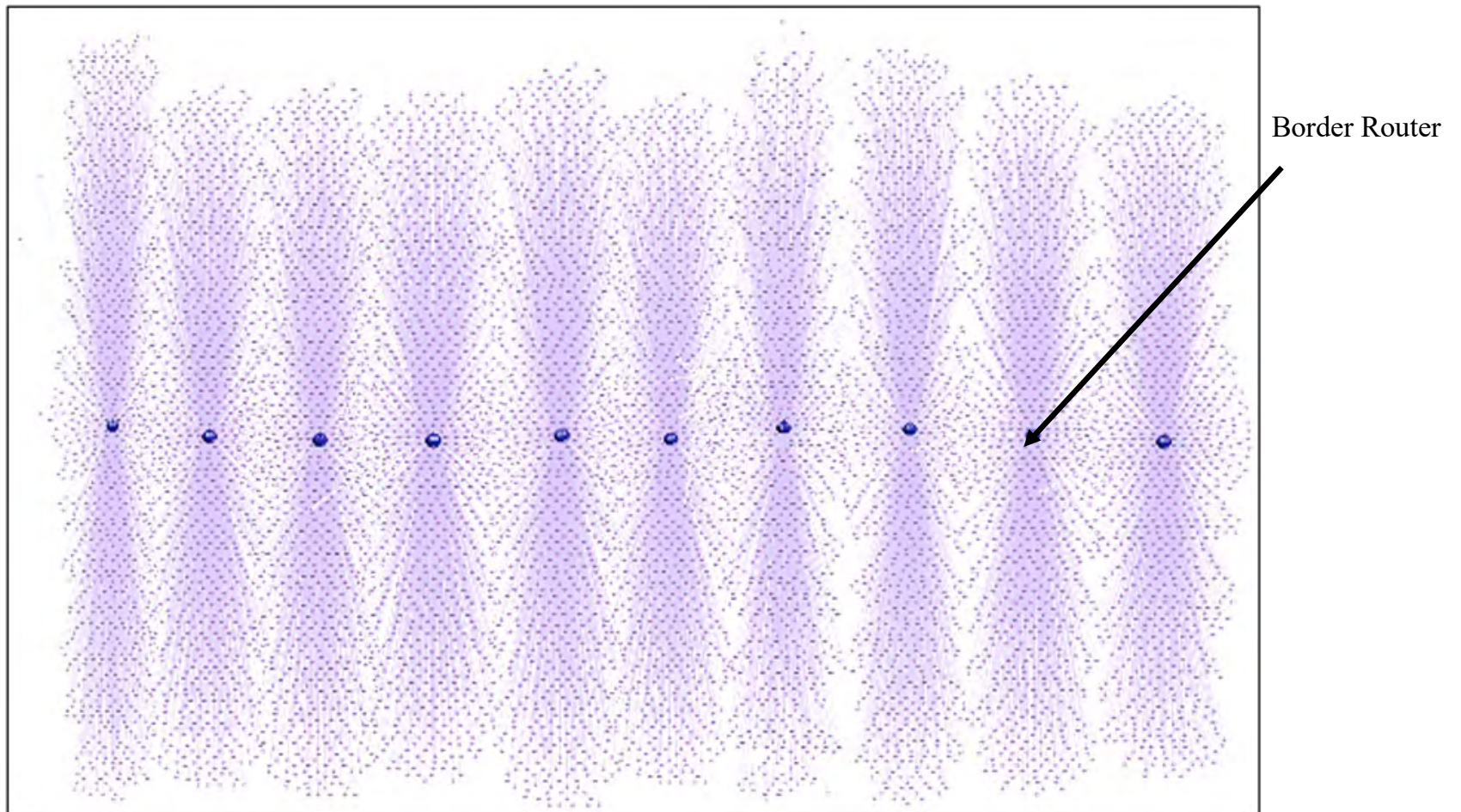
3. Building a mesh network using the Wi-SUN FAN protocol that can be installed on actual devices
(visualization of multi-hop formation status)



4. Packet transmission using the Wi-SUN FAN protocol that can be installed on actual devices
(visualization of transmission status)
[Solid line: route, dotted line: packet transmission]

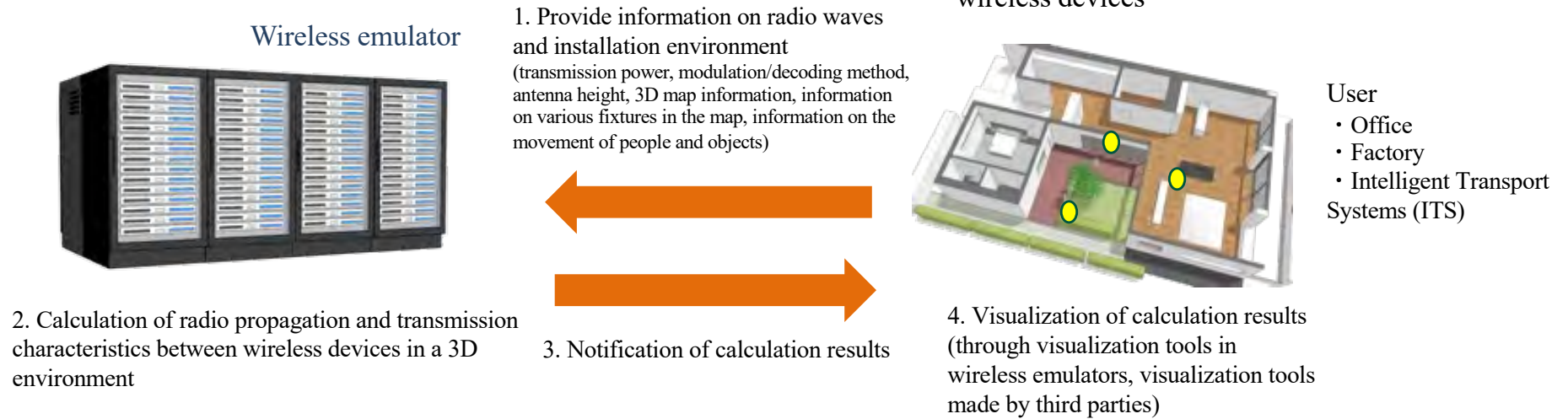


Emulation using 10,000 Wi-SUN FAN virtual radio devices

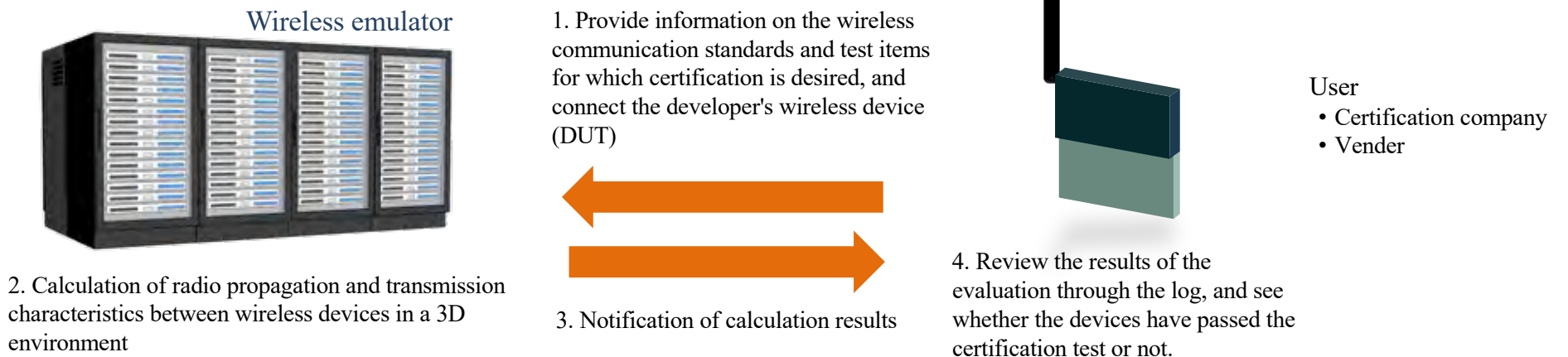


Wireless emulator next step

Design of the location for installing wireless devices



Equipment Certification for Radio Equipment



Conclusions

- Wi-SUN HAN has been installed in tens of millions of devices in Japan, mainly in HAN
- HAN is currently only used for electricity meters, but it is planned to be used for joint meter readings of electricity, gas and water meters
- Wi-SUN FAN can build a mesh network with up to around 20 hops based on IEEE standards, which have been standardized by IEEE802.15 and IEEE 2857
- Wi-SUN FAN is expected to be used in Japan for Field Area Networks between outdoor electricity meters
- By installing Wi-SUN devices in wireless routers, new applications in fields such as medicine, agriculture and factories can be created.
- Wireless emulators are effective as a system that can be used to design large-scale Wi-SUN systems without outdoor experiments

As the Wi-SUN system is a large-scale commercialized system developed by the IEEE 802.15.4 community, it will require continuous expansion in 802.15 community in the future