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Recommendation

ITU-T Q.4071 (12/2023)

SERIES Q: Switching and signalling, and associated measurements and tests

Testing specifications – Testing specifications for IMT-2020 and IoT

The testing of 3D ultra-high density Internet of things networks

ITU-T Q-SERIES RECOMMENDATIONS

Switching and signalling, and associated measurements and tests

SIGNALLING IN THE INTERNATIONAL MANUAL SERVICE	Q.1-Q.3
INTERNATIONAL AUTOMATIC AND SEMI-AUTOMATIC WORKING	Q.4-Q.59
FUNCTIONS AND INFORMATION FLOWS FOR SERVICES IN THE ISDN	Q.60-Q.99
CLAUSES APPLICABLE TO ITU-T STANDARD SYSTEMS	Q.100-Q.119
SPECIFICATIONS OF SIGNALLING SYSTEMS NO. 4, 5, 6, R1 AND R2	Q.120-Q.499
DIGITAL EXCHANGES	Q.500-Q.599
INTERWORKING OF SIGNALLING SYSTEMS	Q.600-Q.699
SPECIFICATIONS OF SIGNALLING SYSTEM NO. 7	Q.700-Q.799
Q3 INTERFACE	Q.800-Q.849
DIGITAL SUBSCRIBER SIGNALLING SYSTEM NO. 1	Q.850-Q.999
PUBLIC LAND MOBILE NETWORK	Q.1000-Q.1099
INTERWORKING WITH SATELLITE MOBILE SYSTEMS	Q.1100-Q.1199
INTELLIGENT NETWORK	Q.1200-Q.1699
SIGNALLING REQUIREMENTS AND PROTOCOLS FOR IMT-2000	Q.1700-Q.1799
SPECIFICATIONS OF SIGNALLING RELATED TO BEARER INDEPENDENT CALL CONTROL (BICC)	Q.1900-Q.1999
BROADBAND ISDN	Q.2000-Q.2999
SIGNALLING REQUIREMENTS AND PROTOCOLS FOR THE NGN	Q.3000-Q.3709
SIGNALLING REQUIREMENTS AND PROTOCOLS FOR SDN	Q.3710-Q.3899
TESTING SPECIFICATIONS	Q.3900-Q.4099
Testing specifications for next generation networks	Q.3900-Q.3999
Testing specifications for SIP-IMS	Q.4000-Q.4039
Testing specifications for Cloud computing	Q.4040-Q.4059
Testing specifications for IMT-2020 and IoT	**Q.4060-Q.4099**
PROTOCOLS AND SIGNALLING FOR PEER-TO-PEER COMMUNICATIONS	Q.4100-Q.4139
PROTOCOLS AND SIGNALLING FOR COMPUTING POWER NETWORKS	Q.4140-Q.4159
PROTOCOLS AND SIGNALLING FOR QUANTUM KEY DISTRIBUTION NETWORKS	Q.4160-Q.4179
SIGNALLING REQUIREMENTS AND PROTOCOLS FOR IMT-2020	Q.5000-Q.5049
COMBATING COUNTERFEITING AND STOLEN ICT DEVICES	Q.5050-Q.5069

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T Q.4071

The testing of 3D ultra-high density Internet of things networks

Summary

Recommendation ITU-T Q.4071 describes testing methods/procedures for 3-dimensional (3D) ultra-high density Internet of things (IoT) networks.

High density and ultra-high density communication networks are currently being introduced based on the density requirements for Internet of things (IoT) devices. For 3-dimensional (3D) ultra-high density networks, the density of IoT devices is 100 devices per cubic metre. Such networks having certain design peculiarities and different fractal figures can be used for their planning. Therefore, it is required to develop models and test methods for high density and ultra-high density networks. New models and test methods for three-dimensional ultra-high density IoT networks will be developed and the structure of a model network for testing will be presented in the proposed Recommendation.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T Q.4071	2023-12-14	11	11.1002/1000/15723

Keywords

3D ultra-high density networks, IoT, testing.

* To access the Recommendation, type the URL https://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID.

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Table of Contents

Recommendation ITU-T Q.4071

The testing of 3D ultra-high density Internet of things networks

1 Scope

This Recommendation describes testing methods/procedures for 3-dimensional (3D) ultra-high density Internet of things (IoT) networks. The Recommendation considers the methods for testing in laboratory conditions using a model network.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

None.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation defines the following terms:

3.1.1 Internet of things (IoT) [b-ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

3.1.2 network 2030 [b-FG-NET2030-Sub-G1]: System, system components and associated aspects that relate to an integrated, highly automated, intelligent partitions of the infrastructures (including heterogeneous communication, compute, storage and network services/applications resources), which contain a number of operator operational domains in all network segments (wired/wireless access, core, edge, space or mixture of segments), that may be accessed by a user from one or more locations.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 3D ultra-high density IoT: Ultra-dense network based on wireless communication technologies, the users and nodes of which are located in three-dimensional space (multi-story buildings and other structures) with a density of 100 devices per cubic metre, where the two-dimensional model cannot adequately describe the network and does not capture properties of network distribution of users and nodes.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3D 3-Dimensional

IoT Internet of Things

SDR Software Defined Radio

UHD Ultra-High Density

5 Conventions

None.

6 Overview

The development of communication networks towards IMT-2020 and beyond takes place both in the direction of creating high density and ultra-high density networks and in the direction of creating ultra-low latency networks. This Recommendation models and tests methods of testing ultra-high density IoT networks in three-dimensional space as the most complex ones. According to existing standards for high density networks, it is required to ensure the quality of service at the placement on a plane of 1 million devices per square kilometre, and for 3D ultra-high density networks at the placement in three-dimensional space (cube) of 100 devices per cubic metre.

For the planning of such networks, methods of fractal geometry are currently used.

6.1 General information

The IoT networks are deployed in a wide variety of infrastructure elements of settlements, as well as in natural objects such as riverbanks, mountain and forest areas, seashores, and so on. Under such conditions, the external environment determines the possible topology of network nodes placement. In this case, the structure of the network to some extent repeats the shape of those objects where it is deployed.

The obvious approach is to copy the properties of the environment of the target network in order to make a plan and transfer it to the environment of the network model. This method is implemented by many wireless network simulation systems.

In high density networks, the number of network elements is so large that the formed network structures can be quite "stable", which allows one to make generalizations and establish their relationship with the environment structure.

Most of the objects of the environment space, in which the network is deployed, i.e., natural and architectural objects have properties of fractal figures. The numerical characteristic of the shape in such a case is the fractal dimension, the concept of which was introduced in the study of self-similar objects.

The purpose of this approach is to approximate the structure of the network model to that of a real network. The complexity of this task consists of the representation and estimation of the similarity of the environment shapes of the planned network and the environment space.

6.2 Representation of the environment space for a high density IoT network

This task can be considered as a selection of a model to represent the environment space of the planned network. The criterion for selecting a model is the greatest similarity between the environment of the target network and the model. The evaluation of similarity presents a certain complexity, firstly, it is necessary to determine how a description of the environment can be set, the model of which should be constructed, and secondly, it is necessary to determine the criterion and method of similarity evaluation.

The fractal figures to represent the environment of the network can be used.

In particular, we note that the poisson field, which would take place in this model in the absence of consideration of the environment space, does not have the properties of self-similarity. The presence and degree of the manifestation of these properties characterizes the structure of the network. This becomes especially important at the high density of network nodes and its planning and design.

The connection of model properties with properties of the object, selected as an environment model, allows to select a network planning for a fractal figure which has similar properties to the properties of objects in the planned structure.

For instance, Hilbert curve can be used as an environment model for urban infrastructure. This is not the only figure whose construction method and fractal properties are known.

Figure 6-1 shows an example of building a network model, where the image of the Sierpinski triangle, obtained at the sixth iteration of the construction is used as a fractal figure of the environment.

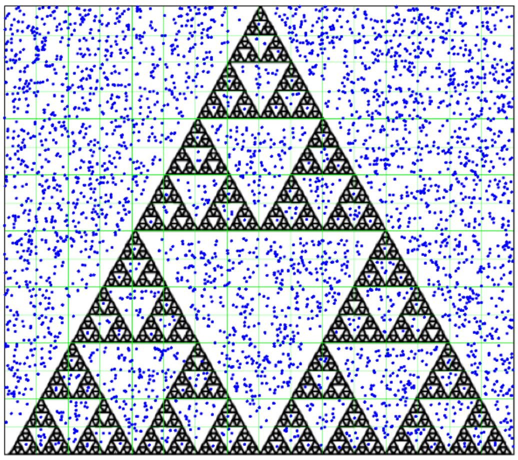

Figure 6-1 – Example of a high density network structure using the Sierpinski triangle

There are quite a few fractal figures, for which the methods of construction and their fractal properties are well known. These figures can also be used in solving the problems of planning the structure of the network, but to select a particular figure, it is necessary to determine the parameters that allow it to make its choice for the specific conditions.

Thus, the task of the methodology is to determine the method of choice and evaluation of the parameters to compare the properties of the planned network structure and the structure of the model to create a methodology for planning and designing high density networks in conditions of the heterogeneous structure of the environment space.

6.3 Fractal figures to represent the non-homogeneous environment space of a high density network

Figure 6-2 shows the construction of fragments of some fractal figures, which can find application in the network planning. These are fractals such as (a) Koch snowflake, (b) Levy C curve, (c) Peano-Gosper curve, (d) Sierpinski curve, (e) Gosper square, and (f) dragon curve.

Comparisons of the given models with different variants of the environment space showed a great similarity of models with rectangular space constructions, and for other models when various kinds of polygons dominate.

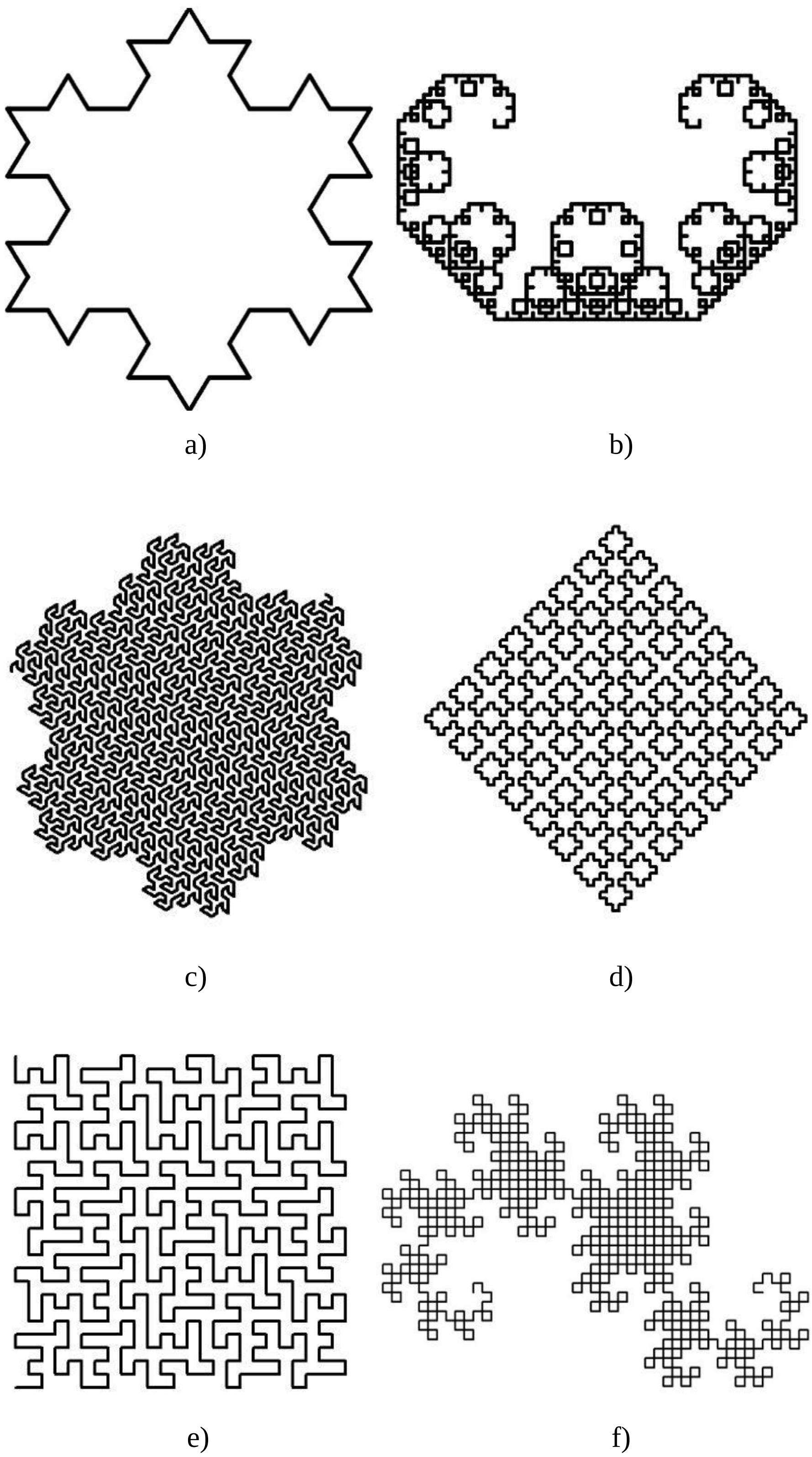

Figure 6-2 – Examples of fractal figures

7 Model network structure for testing 3D ultra-high density IoT networks

Evaluation of the performance of the elements of the high density model network, as well as evaluation of its main parameters with the help of traffic generators is carried out according to the structural diagrams shown in Figures 7-1 and 7-2. The structure of two-dimensional and three-dimensional models are shown in Figures 7-1 and 7-2, respectively.

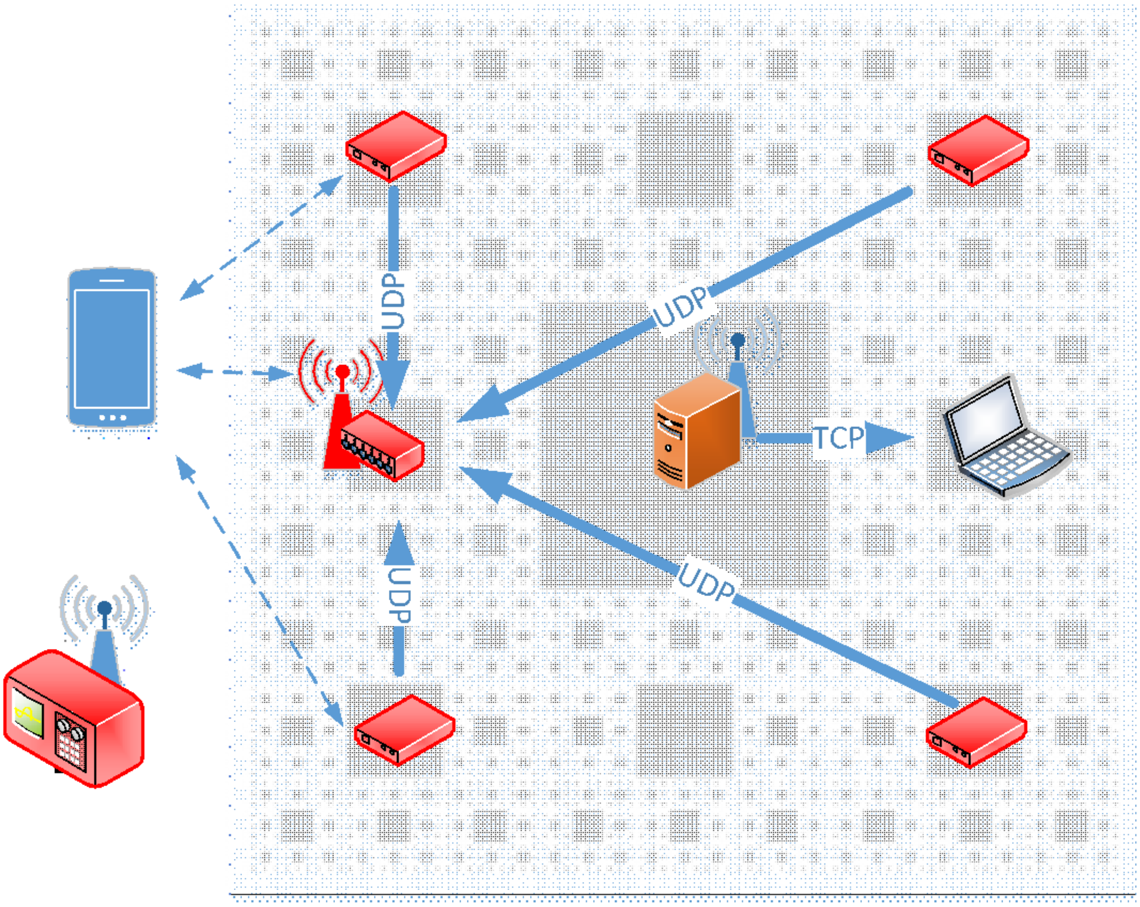

Figure 7-1 – Structural diagram of tests on the two-dimensional network

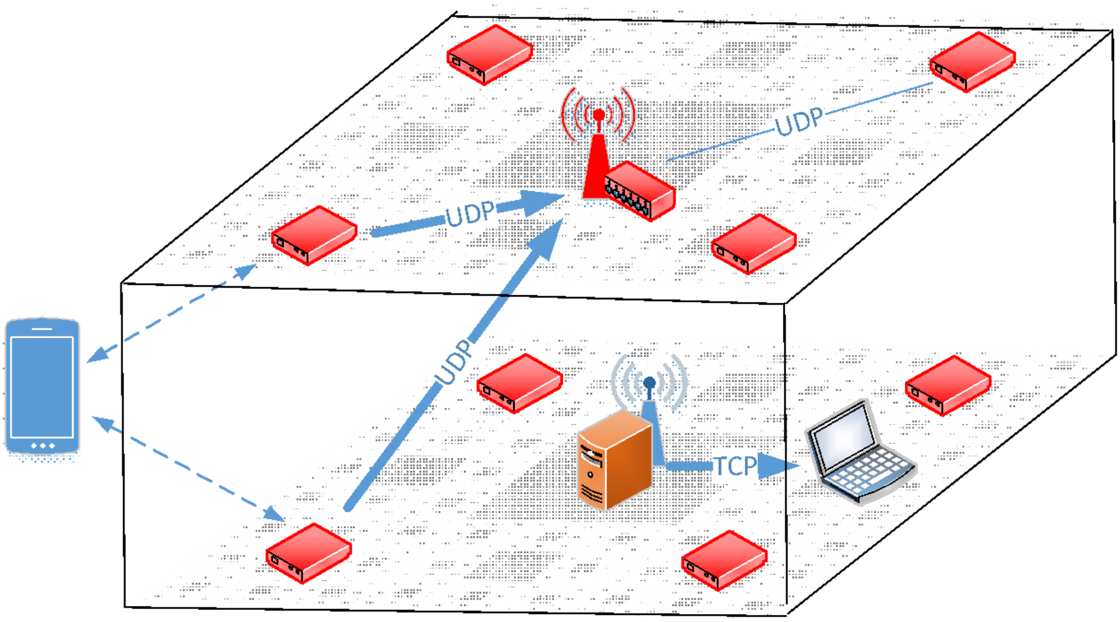

Figure 7-2 – Structural diagram of tests on the three-dimensional network

8 Testing methods for 3D ultra-high density IoT networks

The methodology of model network testing consists of two stages. In the first stage, the performance of elements of the model network is evaluated. In the second stage, the impact of channel load using traffic generators on throughput is estimated.

8.1 Evaluating the performance of the modules of the high density network

Evaluating the performance of the modules of the high density network and their operation as traffic source, destination, and monitor.

Table 1 – Evaluating the performance of the traffic generating device

No	Action	Result
1	Turning on the laptop.	The laptop is turned on and the operating system is started.
2	Running the terminal program.	The terminal program is running.
3	Connecting the traffic destination node via USB.	Receiving a message on the terminal screen from the traffic destination node.
4	Selecting the location of the traffic source node according to the chosen fractal figure.	The traffic source node is installed in the selected location.
5	Turning on the traffic source and the destination nodes.	Receiving information on the terminal screen about traffic reception and logging.
6	Running the software defined radio (SDR).	The results of observing the energy spectrum emitted by the traffic generating node showed activity on channel 1 in the 2.4 GHz band.

Table 2 – Evaluating the performance of the traffic monitoring device

No	Action	Result
1	Turning on the laptop.	The laptop is turned on and the operating system is started.
2	Running the terminal program.	The terminal program is running.
3	Connecting the traffic monitor node via USB.	Receiving a message on the terminal screen from the traffic monitor node.
4	Turning on the traffic source and the destination nodes.	Receiving information on the terminal screen about traffic reception and logging.

8.2 Evaluating the impact of traffic load on IEEE 802.11 channel throughput

Measurement sequence for evaluating the impact of traffic load on the active channel:

Measures taken in the active channel:

1) Connect an IEEE 802.11-compliant access point (router) to a computer that has a file server installed and a file that is effectively large (1 GB), then turn the router's manual channel selection feature on and choose the desired channel, like channel no. 1.

2) Connect a laptop to the access point. The laptop should have software installed that measures the wireless interface's data transfer rate. Connect via the specified channel, create a connection with the file server, and then begin uploading (or downloading) files.

3) Turn on the traffic generator's server and client after the measuring process has begun. Connect new traffic generators to the server at regular intervals.

4) Save the file including the measurements' results, then build a model of how the number of connected traffic generators affects the data transfer rate

Based on the practical measurement results in the nearby channel (Appendix I) it can be recommended to move the generator (or access point) to a nearby channel, such as channel no. 2, before repeating the measurement process that was previously listed.

Appendix I

Examples of measurement results

(This appendix does not form an integral part of this Recommendation.)

An example of the measurement results of the model network testing is shown in Figures I.1 and I.2. The figures show throughput as a function of channel load and inter-channel interference.

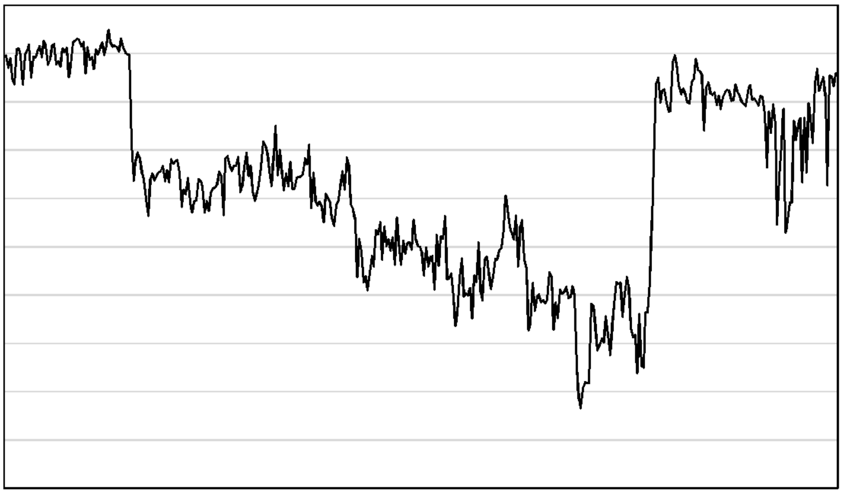

Figure I.1 – Throughput as a function of channel load

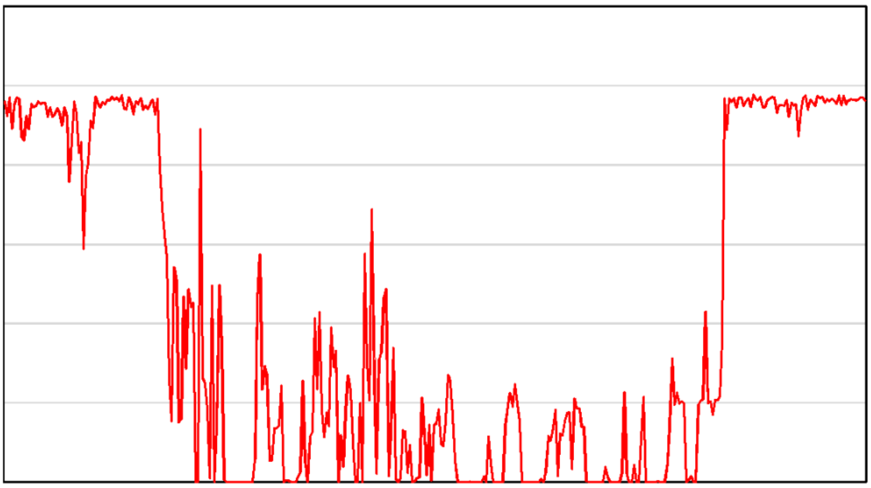

Figure I.2 – Throughput as a function of adjacent channel load (inter-channel interference)

Based on the results of ultra-high density network testing, the characteristics of the achievable throughput as well as the inter-channel interference can be obtained.

Bibliography

[b-ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of the Internet of things*.

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