



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
62/669,461	05/10/2018		280	1426-343.001		

CONFIRMATION NO. 6412

FILING RECEIPT

106622
Blue Capital Law Firm, P.C.
650 Town Center Drive, Suite 1530
Costa Mesa, CA 92626



Date Mailed: 05/17/2018

Receipt is acknowledged of this provisional patent application. It will not be examined for patentability and will become abandoned not later than twelve months after its filing date. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Ko-Chiang Lin, Taipei City, TAIWAN;
Yu-Hsuan Guo, Taipei City, TAIWAN;
Ming-Che Li, Taipei City, TAIWAN;
Hsin-Hsi Tsai, Taipei City, TAIWAN;

Applicant(s)

ASUSTek Computer Inc., Taipei City 112, TAIWAN;

Power of Attorney:

Sang Dang--51186

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 05/16/2018

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 62/669,461**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

Title

METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE
PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at <http://www.uspto.gov/web/offices/pac/doc/general/index.html>.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, <http://www.stopfakes.gov>. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER**Title 35, United States Code, Section 184****Title 37, Code of Federal Regulations, 5.11 & 5.15****GRANTED**

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as

set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign Assets Control, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop technology, manufacture products, deliver services, and grow your business, visit <http://www.SelectUSA.gov> or call +1-202-482-6800.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants: Ko-Chiang Lin; Yu-Hsuan Guo; Ming-Che Li; Hsin-Hsi Tsai
Title: METHOD AND APPARATUS FOR TRIGGERING POWER
HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN
A WIRELESS COMMUNICATION SYSTEM
Serial No.: TBD Filed: Herewith
Examiner: TBD Group Art Unit: TBD
Attorney Docket No.: 1426-343.001 (1070170-US-1)

**CERTIFICATE OF EFS-WEB TRANSMISSION
UNDER 37 CFR § 1.8**

I hereby certify that the enclosed 3 Page Provisional Application Cover Sheet; 8 Page WebADS; 75 Page Specification; and 8 Page Drawings; are being transmitted to the United States Patent and Trademark Office via EFS-Web on May 10, 2018.

Date: May 10, 2018

/Sandy Kim/
Sandy Kim

Mailing Address:

BLUE CAPITAL LAW FIRM, P.C. (Customer No.: 106622)
650 Town Center Drive, Suite 1530
Costa Mesa, California 92626
Tel: 714-839-3800
Fax: 714-795-2995

Electronic Patent Application Fee Transmittal

Application Number:				
Filing Date:				
Title of Invention:	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM			
First Named Inventor/Applicant Name:	Ko-Chiang Lin			
Filer:	Sang N. Dang/Sandy Kim			
Attorney Docket Number:	1426-343.001			
Filed as Large Entity				
Filing Fees for Provisional				
Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Basic Filing:				
PROVISIONAL APPLICATION FILING	1005	1	280	280
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Extension-of-Time:				
Miscellaneous:				
Total in USD (\$)				280

Electronic Acknowledgement Receipt

EFS ID:	32585785
Application Number:	62669461
International Application Number:	
Confirmation Number:	6412
Title of Invention:	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM
First Named Inventor/Applicant Name:	Ko-Chiang Lin
Customer Number:	106622
Filer:	Sang N. Dang/Sandy Kim
Filer Authorized By:	Sang N. Dang
Attorney Docket Number:	1426-343.001
Receipt Date:	10-MAY-2018
Filing Date:	
Time Stamp:	11:41:59
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	\$280
RAM confirmation Number	051018INTEFSW11425900
Deposit Account	
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

File Listing:					
Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Application Data Sheet	WebADS.pdf	144519	no	8
			498ae1744674709d947384c2bcffcb5384a84cad		
Warnings:					
Information:					
2		1426-343-001--Packagev2.pdf	876580	yes	87
			10e5666160c195e1665140e9c63f9b70f5df53f4		
	Multipart Description/PDF files in .zip description				
	Document Description		Start	End	
	Provisional Cover Sheet (SB16)		1	3	
	Specification		4	74	
	Drawings-only black and white line drawings		75	79	
	Specification		80	83	
	Drawings-only black and white line drawings		84	86	
	Miscellaneous Incoming Letter		87	87	
Warnings:					
Information:					
3	Fee Worksheet (SB06)	fee-info.pdf	30015	no	2
			9770990cddfc4c9f5f67644548a4fec7576d2adc		
Warnings:					
Information:					
Total Files Size (in bytes):			1051114		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	1426-343.001
		Application Number	
Title of Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

Secrecy Order 37 CFR 5.2:

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)
--

Inventor Information:

Inventor 1				
Legal Name				
Prefix	Given Name	Middle Name	Family Name	Suffix
	Ko-Chiang		Lin	
Residence Information (Select One) ☐ US Residency ☒ Non US Residency ☐ Active US Military Service				
City	Taipei City	Country of Residence ⁱ	TW	
Mailing Address of Inventor:				
Address 1	No. 15, Lite Rd., Peitou District			
Address 2				
City	Taipei City 112	State/Province	OT	
Postal Code		Country ⁱ	TW	
Inventor 2				
Legal Name				
Prefix	Given Name	Middle Name	Family Name	Suffix
	Yu-Hsuan		Guo	
Residence Information (Select One) ☐ US Residency ☒ Non US Residency ☐ Active US Military Service				
City	Taipei City	Country of Residence ⁱ	TW	
Mailing Address of Inventor:				
Address 1	No. 15, Lite Rd., Peitou District			
Address 2				
City	Taipei City 112	State/Province	OT	
Postal Code		Country ⁱ	TW	

Inventor 3				
Legal Name				
Samsung Electronics Co., Ltd. v. Asus Tech. Licensing				

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	1426-343.001
		Application Number	
Title of Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM		

Prefix	Given Name	Middle Name	Family Name	Suffix
	Ming-Che		Li	
Residence Information (Select One) ☐ US Residency ☒ Non US Residency ☐ Active US Military Service				
City	Taipei City	Country of Residence	TW	

Mailing Address of Inventor:				
Address 1	No. 15, Lite Rd., Peitou District			
Address 2				
City	Taipei City 112	State/Province	OT	
Postal Code		Country	TW	

Inventor 4				
Legal Name				
Prefix	Given Name	Middle Name	Family Name	Suffix
	Hsin-Hsi		Tsai	
Residence Information (Select One) ☐ US Residency ☒ Non US Residency ☐ Active US Military Service				
City	Taipei City	Country of Residence	TW	

Mailing Address of Inventor:				
Address 1	No. 15, Lite Rd., Peitou District			
Address 2				
City	Taipei City 112	State/Province	OT	
Postal Code		Country	TW	

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button.

Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

☐ An Address is being provided for the correspondence Information of this application.

Customer Number	106622		
Email Address		Add Email	Remove Email

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	1426-343.001
		Application Number	
Title of Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM		

Application Information:

Title of the Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM		
Attorney Docket Number	1426-343.001	Small Entity Status Claimed	☐
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	8	Suggested Figure for Publication (if any)	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)
☐ Request Not to Publish. I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application has not and will not be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.					
Please Select One:	☒ Customer Number	☐ US Patent Practitioner	☐ Limited Recognition (37 CFR 11.9)		
Customer Number	106622				
Prefix	Given Name	Middle Name	Family Name	Suffix	Remove
Registration Number					

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	1426-343.001	
		Application Number		
Title of Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM			
Prefix	Given Name	Middle Name	Family Name	Suffix
Remove				
Registration Number				
Additional Representative Information blocks may be generated within this form by selecting the Add button.				

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status		Remove	
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the Add button.			

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX) the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Application Number	Country ⁱ	Filing Date (YYYY-MM-DD)	Access Code ⁱ (if applicable)
Additional Foreign Priority Data may be generated within this form by selecting the Add button.			

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013. NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	1426-343.001
	Application Number	
Title of Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

- ☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.
- ☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	1426-343.001
		Application Number	
Title of Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM		

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

☒ Assignee ☐ Legal Representative under 35 U.S.C. 117 ☐ Joint Inventor

☐ Person to whom the inventor is obligated to assign. ☐ Person who shows sufficient proprietary interest

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name ASUSTek Computer Inc.

Mailing Address Information For Applicant:

Address 1	No. 15, Lite Rd., Peitou District		
Address 2			
City	Taipei City 112	State/Province	OT
Country ⁱ	TW	Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	1426-343.001
		Application Number	
Title of Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM		

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Assignee 1							
Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.							
If the Assignee or Non-Applicant Assignee is an Organization check here. ☐							
Prefix	Given Name	Middle Name	Family Name	Suffix			
Mailing Address Information For Assignee including Non-Applicant Assignee:							
Address 1							
Address 2							
City		State/Province					
Country i			Postal Code				
Phone Number		Fax Number					
Email Address							
Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button.							

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	1426-343.001
		Application Number	
Title of Invention	METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM		

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Sang N. Dang/			Date (YYYY-MM-DD)	
First Name	Sang N.	Last Name	Dang	Registration Number	51186
Additional Signature may be generated within this form by selecting the Add button.					

Provisional Application for Patent Cover Sheet

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)

Inventor(s)

Inventor 1

Remove

Given Name

Middle Name

Family Name

City

State

Country |

Ko-Chiang

Lin

Taipei City

TW

Inventor 2

Remove

Given Name

Middle Name

Family Name

City

State

Country |

Yu-Hsuan

Guo

Taipei City

TW

Inventor 3

Remove

Given Name

Middle Name

Family Name

City

State

Country |

Ming-Che

Li

Taipei City

TW

Inventor 4

Remove

Given Name

Middle Name

Family Name

City

State

Country |

Hsin-Hsi

Tsai

Taipei City

TW

All Inventors Must Be Listed – Additional Inventor Information blocks may be generated within this form by selecting the **Add** button.

Add

Title of Invention

METHOD AND APPARATUS FOR TRIGGERING POWER HEADROOM REPORT FOR MULTIPLE PATHLOSS REFERENCE IN A WIRELESS COMMUNICATION SYSTEM

Attorney Docket Number (if applicable)

1426-343.001

Correspondence Address

Direct all correspondence to (select one):

☒ The address corresponding to Customer Number☐ Firm or Individual Name

Customer Number

106622

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.

☐ Yes, the invention was made by an agency of the United States Government. The U.S. Government agency name is:

☐ Yes, the invention was under a contract with an agency of the United States Government. The name of the U.S. Government agency and Government contract number are:

Entity Status**Applicant asserts small entity status under 37 CFR 1.27 or applicant certifies micro entity status under 37 CFR 1.29**

- ☐ Applicant asserts small entity status under 37 CFR 1.27
- ☐ Applicant certifies micro entity status under 37 CFR 1.29. Applicant must attach form PTO/SB/15A or B or equivalent.
- ☒ No

Warning

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

Signature

Please see 37 CFR 1.4(d) for the form of the signature.

Signature	/Sang N. Dang/			Date (YYYY-MM-DD)	2018-05-10
First Name	Sang N.	Last Name	Dang	Registration Number (If appropriate)	51186

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **This form can only be used when in conjunction with EFS-Web. If this form is mailed to the USPTO, it may cause delays in handling the provisional application.**

Method and apparatus for triggering power headroom report for multiple pathloss reference in a wireless communication system

Background

Table of abbreviations:

Abbreviation	Full name
3GPP	3 rd Generation Partnership Project
ACK	acknowledgement
BSR	buffer status report
C-RNTI	Cell Radio Network Temporary Identifier
CQI	Channel Quality Indicator
CSI	Channel State Information
eIMTA	Enhanced Interference Mitigation and Traffic Adaptation
eNB	Evolved Node B
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
HARQ	Hybrid Automatic Repeat Request
L1	Layer 1
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MAC	Medium Access Control
NACK	negative acknowledgement
NDI	New data indicator
OFDM	Orthogonal Frequency Division Multiplexing
PDCCH	Physical Downlink Control Channel
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
RN	Relay Node
RRC	Radio Resource Control
SDU	Service Data Unit
SFN	System Frame Number
SpCell	Special Cell
SPS	Semi-Persistent Scheduling
SR	Scheduling Request
SRS	Sounding Reference Signal
TAG	Timing Advance Group
TDD	Time Division Duplex
TS	Technical Specification
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UL-SCH	Uplink Shared Channel

As described in [8] and its associated non-provisional [9], PHR triggering for beam operation

were disclosed. The contents from the two applications are incorporated below. Further details on top of them or embodiment(s) independent from them are disclosed.

As described in [1], in lower frequency bands (e.g. current LTE bands < 6GHz) the required cell coverage may be provided by forming a wide sector beam for transmitting downlink common channels. However, utilizing wide sector beam on higher frequencies (>> 6GHz) the cell coverage is reduced with same antenna gain. Thus, in order to provide required cell coverage on higher frequency bands, higher antenna gain is needed to compensate the increased path loss. To increase the antenna gain over a wide sector beam, larger antenna arrays (number of antenna elements ranging from tens to hundreds) are used to form high gain beams.

As a consequence the high gain beams are narrow compared to a wide sector beam so multiple beams for transmitting downlink common channels are needed to cover the required cell area. The number of concurrent high gain beams that access point is able to form may be limited by the cost and complexity of the utilized transceiver architecture. In practice, on higher frequencies, the number of concurrent high gain beams is much less than the total number of beams required to cover the cell area. In other words, the access point is able to cover only part of the cell area by using a subset of beams at any given time.

As described in [2], beamforming is a signal processing technique used in antenna arrays for directional signal transmission/reception. With beamforming, a beam can be formed by combining elements in a phased array of antennas in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Different beams can be utilized simultaneously using multiple arrays of antennas.

Beamforming can be categorized into three types of implementation: digital beamforming, hybrid beamforming, and analog beamforming. For digital beamforming, the beam is generated on the digital domain, i.e. the weighting of each antenna element can be controlled by baseband (e.g. connected to a TXRU). Therefore it is very easy to tune the beam direction of each subband differently across the system bandwidth. Also, to change beam direction from time to time does not require any switching time between OFDM symbols. All beams whose directions cover the whole coverage can be generated simultaneously. However, this structure requires (almost) one-to-one mapping between TXRU (transceiver/RF chain) and antenna element and is quite complicated as the number of antenna element increases and system bandwidth increases (also heat problem exists). For Analog beamforming, the beam is generated on the analog domain, i.e. the weighting of each antenna element can be controlled by an amplitude/phase shifter in the RF circuit. Since the weighing is purely controlled by the circuit, the same beam direction would apply on the whole system bandwidth. Also, if beam direction is to be changed, switching time is required. The number of beam generated simultaneous by an analog beamforming depends on the number of TXRU. Note that for a given size of array, the increase of TXRU may decrease the antenna element of each beam, such that wider beam would be generated. In short, analog beamforming could avoid the complexity and heat problem of digital beamforming, while is more restricted in operation. Hybrid beamforming can be considered as a compromise between analog and digital beamforming, where the beam can come from both analog and digital domain. The three types of beamforming is shown in Fig.1

In [3], an eNB may have multiple TRPs (either centralized or distributed). Each TRP can form multiple beams. The number of beams and the number of simultaneous beams in the

time/frequency domain depend on the number of antenna array elements and the RF at the TRP.

Potential mobility type for NR can be listed:

- Intra-TRP mobility
- Inter-TRP mobility
- Inter-NR eNB mobility

In [4], reliability of a system purely relying on beamforming and operating in higher frequencies might be challenging, since the coverage might be more sensitive to both time and space variations. As a consequence of that the SINR of that narrow link can drop much quicker than in the case of LTE.

Using antenna arrays at access nodes with the number of elements in the hundreds, fairly regular grid-of-beams coverage patterns with tens or hundreds of candidate beams per node may be created. The coverage area of an individual beam from such array may be small, down to the order of some tens of meters in width. As a consequence, channel quality degradation outside the current serving beam area is quicker than in the case of wide area coverage, as provided by LTE.

With the support of beam operation and TRP, a cell may have multiple choices to schedule a UE. For example, there may be multiple beams from a TRP transmitting the same data to the UE, which can provide more reliability for the transmission. Alternatively, multiple beams from multiple TRPs transmit the same data to the UE. To increase the throughput, it is also possible for a single TRP to transmit different data on different beams for the UE. Also, multiple TRPs can transmit different data on different beams to the UE.

To maintain the balance between the UL transmission performance and UE power consumption as well as interference mitigation, UE transmission power is properly controlled. The power may be controlled by some open loop parameter, e.g. the required received power, pathloss between UE and base station. It may also be controlled based on some close loop parameter, e.g. the power control command sent from the base station to the UE. Some more details can be found in below quotation [5]:

5 Power control

Downlink power control determines the Energy Per Resource Element (EPRE). The term resource element energy denotes the energy prior to CP insertion. The term resource element energy also denotes the average energy taken over all constellation points for the modulation scheme applied. Uplink power control determines the average power over a SC-FDMA symbol in which the physical channel is transmitted.

5.1 Uplink power control

Uplink power control controls the transmit power of the different uplink physical channels.

If a UE is configured with a LAA SCell for uplink transmissions, the UE shall apply the procedures described for PUSCH and SRS in this clause assuming frame structure type 1 for the LAA SCell unless stated otherwise.

For PUSCH, the transmit power $\hat{P}_{\text{PUSCH},c}(i)$ defined in subclause 5.1.1, is first scaled by the ratio of the number of antennas ports with a non-zero PUSCH transmission to the number of configured antenna ports for the transmission scheme. The resulting scaled power is then split equally across the antenna ports on which the non-zero PUSCH is transmitted.

For PUCCH or SRS, the transmit power $\hat{P}_{\text{PUCCH}}(i)$, defined in subclause 5.1.1.1, or $\hat{P}_{\text{SRS},c}(i)$ is split equally across the configured antenna ports for PUCCH or SRS. $\hat{P}_{\text{SRS},c}(i)$ is the linear value of $P_{\text{SRS},c}(i)$ defined in subclause 5.1.3.

A cell wide overload indicator (OI) and a High Interference Indicator (HII) to control UL interference are defined in [9].

For a serving cell with frame structure type 1, a UE is not expected to be configured with *UplinkPowerControlDedicated-v12x0*.

5.1.1 Physical uplink shared channel

If the UE is configured with a SCG, the UE shall apply the procedures described in this clause for both MCG and SCG

- When the procedures are applied for MCG, the terms ‘secondary cell’, ‘secondary cells’, ‘serving cell’, ‘serving cells’ in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the MCG respectively.
- When the procedures are applied for SCG, the terms ‘secondary cell’, ‘secondary cells’, ‘serving cell’, ‘serving cells’ in this clause refer to secondary cell, secondary cells (not including PSCell), serving cell, serving cells belonging to the SCG respectively. The term ‘primary cell’ in this clause refers to the PSCell of the SCG.

If the UE is configured with a PUCCH-SCell, the UE shall apply the procedures described in this clause for both primary PUCCH group and secondary PUCCH group

- When the procedures are applied for primary PUCCH group, the terms ‘secondary cell’, ‘secondary cells’, ‘serving cell’, ‘serving cells’ in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the primary PUCCH group respectively.
- When the procedures are applied for secondary PUCCH group, the terms ‘secondary cell’, ‘secondary cells’, ‘serving cell’, ‘serving cells’ in this clause refer to secondary cell, secondary cells, serving cell, serving cells belonging to the secondary PUCCH group respectively.

5.1.1.1 UE behaviour

The setting of the UE Transmit power for a Physical Uplink Shared Channel (PUSCH) transmission is defined as follows.

If the UE transmits PUSCH without a simultaneous PUCCH for the serving cell c , then the UE transmit power $P_{\text{PUSCH},c}(i)$ for PUSCH transmission in subframe i for the serving cell c is given by

$$P_{\text{PUSCH},c}(i) = \min \left\{ P_{\text{CMAX},c}(i), 10 \log_{10}(M_{\text{PUSCH},c}(i)) + P_{\text{O_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + \Delta_{\text{TF},c}(i) + f_c(i) \right\} \quad [\text{dBm}]$$

If the UE transmits PUSCH simultaneous with PUCCH for the serving cell c , then the UE transmit power $P_{\text{PUSCH},c}(i)$ for the PUSCH transmission in subframe i for the serving cell c is given by

$$P_{\text{PUSCH},c}(i) = \min \left\{ 10 \log_{10}(\hat{P}_{\text{CMAX},c}(i) - \hat{P}_{\text{PUCCH}}(i)), 10 \log_{10}(M_{\text{PUSCH},c}(i)) + P_{\text{O_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + \Delta_{\text{TF},c}(i) + f_c(i) \right\} \quad [\text{dBm}]$$

If the UE is not transmitting PUSCH for the serving cell c , for the accumulation of TPC command received with DCI format 3/3A for PUSCH, the UE shall assume that the UE transmit power $P_{\text{PUSCH},c}(i)$ for the PUSCH transmission in subframe i for the serving cell c is computed by

$$P_{\text{PUSCH},c}(i) = \min \{ P_{\text{CMAX},c}(i), P_{\text{O_PUSCH},c}(1) + \alpha_c(1) \cdot PL_c + f_c(i) \} \quad [\text{dBm}]$$

where,

- $P_{\text{CMAX},c}(i)$ is the configured UE transmit power defined in [6] in subframe i for serving cell c and $\hat{P}_{\text{CMAX},c}(i)$ is the linear value of $P_{\text{CMAX},c}(i)$. If the UE transmits PUCCH without PUSCH in subframe i for the serving cell c , for the accumulation of TPC command received with DCI format 3/3A for PUSCH, the UE shall assume $P_{\text{CMAX},c}(i)$ as given by subclause 5.1.2.1. If the UE does not transmit PUCCH and PUSCH in subframe i for the serving cell c , for the accumulation of TPC command received with DCI format 3/3A for PUSCH, the UE shall compute $P_{\text{CMAX},c}(i)$ assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB and $\Delta T_C=0$ dB, where MPR, A-MPR, P-MPR and ΔT_C are defined in [6].
- $\hat{P}_{\text{PUCCH}}(i)$ is the linear value of $P_{\text{PUCCH}}(i)$ defined in subclause 5.1.2.1
- $M_{\text{PUSCH},c}(i)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks valid for subframe i and serving cell c .
- If the UE is configured with higher layer parameter *UplinkPowerControlDedicated-v12x0* for serving cell c and if subframe i belongs to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12*,
 - when $j=0$, $P_{\text{O_PUSCH},c}(0) = P_{\text{O_UE_PUSCH},c,2}(0) + P_{\text{O_NOMINAL_PUSCH},c,2}(0)$, where $j=0$ is used for PUSCH (re)transmissions corresponding to a semi-persistent grant. $P_{\text{O_UE_PUSCH},c,2}(0)$ and $P_{\text{O_NOMINAL_PUSCH},c,2}(0)$ are the parameters *p0-UE-PUSCH-Persistent-SubframeSet2-r12* and *p0-NominalPUSCH-Persistent-SubframeSet2-r12* respectively provided by higher layers, for each serving cell c .
 - when $j=1$, $P_{\text{O_PUSCH},c}(1) = P_{\text{O_UE_PUSCH},c,2}(1) + P_{\text{O_NOMINAL_PUSCH},c,2}(1)$, where $j=1$ is used for PUSCH (re)transmissions corresponding to a dynamic scheduled grant. $P_{\text{O_UE_PUSCH},c,2}(1)$ and $P_{\text{O_NOMINAL_PUSCH},c,2}(1)$ are the parameters *p0-UE-PUSCH-SubframeSet2-r12* and *p0-NominalPUSCH-SubframeSet2-r12* respectively, provided by higher layers for serving cell c .
 - when $j=2$, $P_{\text{O_PUSCH},c}(2) = P_{\text{O_UE_PUSCH},c}(2) + P_{\text{O_NOMINAL_PUSCH},c}(2)$ where $P_{\text{O_UE_PUSCH},c}(2) = 0$ and $P_{\text{O_NOMINAL_PUSCH},c}(2) = P_{\text{O_PRE}} + \Delta_{\text{PREAMBLE_Msg3}}$, where the

parameter *preambleInitialReceivedTargetPower* [8] (P_{O_PRE}) and $\Delta_{PREAMBLE_Msg3}$ are signalled from higher layers for serving cell c , where $j=2$ is used for PUSCH (re)transmissions corresponding to the random access response grant.

Otherwise

- $P_{O_PUSCH,c}(j)$ is a parameter composed of the sum of a component $P_{O_NOMINAL_PUSCH,c}(j)$ provided from higher layers for $j=0$ and 1 and a component $P_{O_UE_PUSCH,c}(j)$ provided by higher layers for $j=0$ and 1 for serving cell c . For PUSCH (re)transmissions corresponding to a semi-persistent grant then $j=0$, for PUSCH (re)transmissions corresponding to a dynamic scheduled grant then $j=1$ and for PUSCH (re)transmissions corresponding to the random access response grant then $j=2$. $P_{O_UE_PUSCH,c}(2) = 0$ and $P_{O_NOMINAL_PUSCH,c}(2) = P_{O_PRE} + \Delta_{PREAMBLE_Msg3}$, where the parameter *preambleInitialReceivedTargetPower* [8] (P_{O_PRE}) and $\Delta_{PREAMBLE_Msg3}$ are signalled from higher layers for serving cell c .
- If the UE is configured with higher layer parameter *UplinkPowerControlDedicated-v12x0* for serving cell c and if subframe i belongs to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12*,
 - For $j=0$ or 1 , $\alpha_c(j) = \alpha_{c,2} \in \{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$. $\alpha_{c,2}$ is the parameter *alpha-SubframeSet-r12* provided by higher layers for each serving cell c .
 - For $j=2$, $\alpha_c(j) = 1$.

Otherwise

- For $j=0$ or 1 , $\alpha_c \in \{0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$ is a 3-bit parameter provided by higher layers for serving cell c . For $j=2$, $\alpha_c(j) = 1$.
- PL_c is the downlink path loss estimate calculated in the UE for serving cell c in dB and $PL_c = referenceSignalPower - \text{higher layer filtered RSRP}$, where *referenceSignalPower* is provided by higher layers and RSRP is defined in [5] for the reference serving cell and the higher layer filter configuration is defined in [11] for the reference serving cell.
 - If serving cell c belongs to a TAG containing the primary cell then, for the uplink of the primary cell, the primary cell is used as the reference serving cell for determining *referenceSignalPower* and higher layer filtered RSRP. For the uplink of the secondary cell, the serving cell configured by the higher layer parameter *pathlossReferenceLinking* defined in [11] is used as the reference serving cell for determining *referenceSignalPower* and higher layer filtered RSRP.
 - If serving cell c belongs to a TAG containing the PSCell then, for the uplink of the PSCell, the PSCell is used as the reference serving cell for determining *referenceSignalPower* and higher layer filtered RSRP; for the uplink of the secondary cell other than PSCell, the serving cell configured by the higher layer parameter *pathlossReferenceLinking* defined in [11] is used as the reference serving cell for determining *referenceSignalPower* and higher layer filtered RSRP.
 - If serving cell c belongs to a TAG not containing the primary cell or PSCell then serving cell c is used as the reference serving cell for determining *referenceSignalPower* and higher layer filtered RSRP.

- $\Delta_{TF,c}(i) = 10 \log_{10} \left(\left(2^{BP_{RE} \cdot K_s} - 1 \right) \cdot \beta_{offset}^{PUSCH} \right)$ for $K_s = 1.25$ and 0 for $K_s = 0$ where K_s is given by the parameter *deltaMCS-Enabled* provided by higher layers for each serving cell c . BP_{RE} and β_{offset}^{PUSCH} , for each serving cell c , are computed as below. $K_s = 0$ for transmission mode 2.
- $BP_{RE} = O_{CQI} / N_{RE}$ for control data sent via PUSCH without UL-SCH data and $\sum_{r=0}^{C-1} K_r / N_{RE}$ for other cases.
 - where C is the number of code blocks, K_r is the size for code block r , O_{CQI} is the number of CQI/PMI bits including CRC bits and N_{RE} is the number of resource elements determined as $N_{RE} = M_{sc}^{PUSCH-initial} \cdot N_{symb}^{PUSCH-initial}$, where C , K_r , $M_{sc}^{PUSCH-initial}$ and $N_{symb}^{PUSCH-initial}$ are defined in [4].
- $\beta_{offset}^{PUSCH} = \beta_{offset}^{CQI}$ for control data sent via PUSCH without UL-SCH data and 1 for other cases.
- $\delta_{PUSCH,c}$ is a correction value, also referred to as a TPC command and is included in PDCCH/EPDCCH with DCI format 0/4 or in MPDCCH with DCI format 6-0A for serving cell c or jointly coded with other TPC commands in PDCCH/MPDCCH with DCI format 3/3A whose CRC parity bits are scrambled with TPC-PUSCH-RNTI. If the UE is configured with higher layer parameter *UplinkPowerControlDedicated-v12x0* for serving cell c and if subframe i belongs to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12*, the current PUSCH power control adjustment state for serving cell c is given by $f_{c,2}(i)$, and the UE shall use $f_{c,2}(i)$ instead of $f_c(i)$ to determine $P_{PUSCH,c}(i)$. Otherwise, the current PUSCH power control adjustment state for serving cell c is given by $f_c(i)$. $f_{c,2}(i)$ and $f_c(i)$ are defined by:
 - $f_c(i) = f_c(i-1) + \delta_{PUSCH,c}(i - K_{PUSCH})$ and $f_{c,2}(i) = f_{c,2}(i-1) + \delta_{PUSCH,c}(i - K_{PUSCH})$ if accumulation is enabled based on the parameter *Accumulation-enabled* provided by higher layers or if the TPC command $\delta_{PUSCH,c}$ is included in a PDCCH/EPDCCH with DCI format 0 or in a MPDCCH with DCI format 6-0A for serving cell c where the CRC is scrambled by the Temporary C-RNTI
 - where $\delta_{PUSCH,c}(i - K_{PUSCH})$ was signalled on PDCCH/EPDCCH with DCI format 0/4 or MPDCCH with DCI format 6-0A or PDCCH/MPDCCH with DCI format 3/3A on subframe $i - K_{PUSCH}$, and where $f_c(0)$ is the first value after reset of accumulation. For a BL/CE UE configured with CEModeA, subframe $i - K_{PUSCH}$ is the last subframe in which the MPDCCH with DCI format 6-0A or MPDCCH with DCI format 3/3A is transmitted.
 - The value of K_{PUSCH} is
 - For FDD or FDD-TDD and serving cell frame structure type 1, $K_{PUSCH} = 4$
 - For TDD, if the UE is configured with more than one serving cell and the TDD UL/DL configuration of at least two configured serving cells is not the same, or if the UE is configured with the parameter *EIMTA-MainConfigServCell-r12* for at least one serving cell, or for FDD-TDD and serving cell frame structure type 2, the "TDD UL/DL configuration" refers to the UL-reference UL/DL configuration (defined in subclause 8.0) for serving cell c .
 - For TDD UL/DL configurations 1-6, K_{PUSCH} is given in Table 5.1.1.1-1

- For TDD UL/DL configuration 0
 - If the PUSCH transmission in subframe 2 or 7 is scheduled with a PDCCH/EPDCCH of DCI format 0/4 or a MPDCCH of DCI format 6-0A in which the LSB of the UL index is set to 1, $K_{PUSCH} = 7$
 - For all other PUSCH transmissions, K_{PUSCH} is given in Table 5.1.1.1-1.
- For serving cell c and a non-BL/CE UE, the UE attempts to decode a PDCCH/EPDCCH of DCI format 0/4 with the UE's C-RNTI or DCI format 0 for SPS C-RNTI and a PDCCH of DCI format 3/3A with this UE's TPC-PUSCH-RNTI in every subframe except when in DRX or where serving cell c is deactivated.
- For serving cell c and a BL/CE UE configured with CEModeA, the UE attempts to decode a MPDCCH of DCI format 6-0A with the UE's C-RNTI or SPS C-RNTI and a MPDCCH of DCI format 3/3A with this UE's TPC-PUSCH-RNTI in every BL/CE downlink subframe except when in DRX
- For a non-BL/CE UE, if DCI format 0/4 for serving cell c and DCI format 3/3A are both detected in the same subframe, then the UE shall use the $\delta_{PUSCH,c}$ provided in DCI format 0/4.
- For a BL/CE UE configured with CEModeA, if DCI format 6-0A for serving cell c and DCI format 3/3A are both detected in the same subframe, then the UE shall use the $\delta_{PUSCH,c}$ provided in DCI format 6-0A.
- $\delta_{PUSCH,c} = 0$ dB for a subframe where no TPC command is decoded for serving cell c or where DRX occurs or i is not an uplink subframe in TDD or FDD-TDD and serving cell c frame structure type 2.
- The $\delta_{PUSCH,c}$ dB accumulated values signalled on PDCCH/EPDCCH with DCI format 0/4 or MPDCCH with DCI format 6-0A are given in Table 5.1.1.1-2. If the PDCCH/EPDCCH with DCI format 0 or MPDCCH with DCI format 6-0A is validated as a SPS activation or release PDCCH/EPDCCH/MPDCCH, then $\delta_{PUSCH,c}$ is 0dB.
- The δ_{PUSCH} dB accumulated values signalled on PDCCH/MPDCCH with DCI format 3/3A are one of SET1 given in Table 5.1.1.1-2 or SET2 given in Table 5.1.1.1-3 as determined by the parameter *TPC-Index* provided by higher layers.
- If UE has reached $P_{MAX,c}(i)$ for serving cell c , positive TPC commands for serving cell c shall not be accumulated
- If UE has reached minimum power, negative TPC commands shall not be accumulated
- If the UE is not configured with higher layer parameter *UplinkPowerControlDedicated-v12x0* for serving cell c , the UE shall reset accumulation
 - For serving cell c , when $P_{O_UE_PUSCH,c}$ value is changed by higher layers
 - For serving cell c , when the UE receives random access response message for serving cell c
- If the UE is configured with higher layer parameter *UplinkPowerControlDedicated-v12x0* for serving cell c ,
 - the UE shall reset accumulation corresponding to $f_c(*)$ for serving cell c
 - when $P_{O_UE_PUSCH,c}$ value is changed by higher layers

- when the UE receives random access response message for serving cell c
- the UE shall reset accumulation corresponding to $f_{c,2}(*)$ for serving cell c
- when $P_{O_UE_PUSCH,c,2}$ value is changed by higher layers
- If the UE is configured with higher layer parameter *UplinkPowerControlDedicated-v12x0* for serving cell c and
 - if subframe i belongs to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12* $f_c(i) = f_c(i-1)$
 - if subframe i does not belong to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12* $f_{c,2}(i) = f_{c,2}(i-1)$
- $f_c(i) = \delta_{PUSCH,c}(i - K_{PUSCH})$ and $f_{c,2}(i) = \delta_{PUSCH,c}(i - K_{PUSCH})$ if accumulation is not enabled for serving cell c based on the parameter *Accumulation-enabled* provided by higher layers
- where $\delta_{PUSCH,c}(i - K_{PUSCH})$ was signalled on PDCCH/EPDCCH with DCI format 0/4 or MPDCCH with DCI format 6-0A for serving cell c on subframe $i - K_{PUSCH}$. For a BL/CE UE configured with CEModeA, subframe $i - K_{PUSCH}$ is the last subframe in which the MPDCCH with DCI format 6-0A or MPDCCH with DCI format 3/3A is transmitted.
- The value of K_{PUSCH} is
 - For FDD or FDD-TDD and serving cell frame structure type 1, $K_{PUSCH} = 4$
 - For TDD, if the UE is configured with more than one serving cell and the TDD UL/DL configuration of at least two configured serving cells is not the same, or if the UE is configured with the parameter *EIMTA-MainConfigServCell-r12* for at least one serving cell, or FDD-TDD and serving cell frame structure type 2, the "TDD UL/DL configuration" refers to the UL-reference UL/DL configuration (defined in subclause 8.0) for serving cell c .
 - For TDD UL/DL configurations 1-6, K_{PUSCH} is given in Table 5.1.1.1-1.
 - For TDD UL/DL configuration 0
 - If the PUSCH transmission in subframe 2 or 7 is scheduled with a PDCCH/EPDCCH of DCI format 0/4 or a MPDCCH with DCI format 6-0A in which the LSB of the UL index is set to 1, $K_{PUSCH} = 7$
 - For all other PUSCH transmissions, K_{PUSCH} is given in Table 5.1.1.1-1.
- The $\delta_{PUSCH,c}$ dB absolute values signalled on PDCCH/EPDCCH with DCI format 0/4 or a MPDCCH with DCI format 6-0A are given in Table 5.1.1.1-2. If the PDCCH/EPDCCH with DCI format 0 or a MPDCCH with DCI format 6-0A is validated as a SPS activation or release PDCCH/EPDCCH/MPDCCH, then $\delta_{PUSCH,c}$ is 0dB.
- for a non-BL/CE UE, $f_c(i) = f_c(i-1)$ and $f_{c,2}(i) = f_{c,2}(i-1)$ for a subframe where no PDCCH/EPDCCH with DCI format 0/4 is decoded for serving cell c or where DRX occurs or i is not an uplink subframe in TDD or FDD-TDD and serving cell c frame structure type 2.

- for a BL/CE UE configured with CEModeA, $f_c(i) = f_c(i-1)$ and $f_{c,2}(i) = f_{c,2}(i-1)$ for a subframe where no MPDCCH with DCI format 6-0A is decoded for serving cell c or where DRX occurs or i is not an uplink subframe in TDD.
- If the UE is configured with higher layer parameter *UplinkPowerControlDedicated-v12x0* for serving cell c and
 - if subframe i belongs to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12* $f_c(i) = f_c(i-1)$
 - if subframe i does not belong to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12* $f_{c,2}(i) = f_{c,2}(i-1)$
- For both types of $f_c(*)$ (accumulation or current absolute) the first value is set as follows:
 - If $P_{O_UE_PUSCH,c}$ value is changed by higher layers and serving cell c is the primary cell or, if $P_{O_UE_PUSCH,c}$ value is received by higher layers and serving cell c is a Secondary cell
 - $f_c(0) = 0$
 - Else
 - If the UE receives the random access response message for a serving cell c
 - $f_c(0) = \Delta P_{rampup,c} + \delta_{msg2,c}$, where
 - $\delta_{msg2,c}$ is the TPC command indicated in the random access response corresponding to the random access preamble transmitted in the serving cell c , see subclause 6.2, and

$$\Delta P_{rampup,c} = \min \left[\left[\max \left(0, P_{C_{MAX},c} - \left(\begin{array}{l} 10 \log_{10}(M_{PUSCH,c}(0)) \\ + P_{O_PUSCH,c}(2) + \delta_{msg2} \\ + \alpha_c(2) \cdot PL + \Delta_{TF,c}(0) \end{array} \right) \right) \right], \right. \\ \left. \Delta P_{rampuprequested,c} \right] \text{ and } \Delta P_{rampuprequested,c} \text{ is provided by higher layers}$$

and corresponds to the total power ramp-up requested by higher layers from the first to the last preamble in the serving cell c , $M_{PUSCH,c}(0)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks valid for the subframe of first PUSCH transmission in the serving cell c , and $\Delta_{TF,c}(0)$ is the power adjustment of first PUSCH transmission in the serving cell c .

- If $P_{O_UE_PUSCH,c,2}$ value is received by higher layers for a serving cell c .
 - $f_{c,2}(0) = 0$

Table 5.1.1.1-1: K_{PUSCH} for TDD configuration 0-6

TDD UL/DL Configuratio n	subframe number i									
	0	1	2	3	4	5	6	7	8	9
0	-	-	6	7	4	-	-	6	7	4
1	-	-	6	4	-	-	-	6	4	-
2	-	-	4	-	-	-	-	4	-	-
3	-	-	4	4	4	-	-	-	-	-
4	-	-	4	4	-	-	-	-	-	-
5	-	-	4	-	-	-	-	-	-	-
6	-	-	7	7	5	-	-	7	7	-

Table 5.1.1.1-2: Mapping of TPC Command Field in DCI format 0/3/4/6-0A to absolute and accumulated $\delta_{PUSCH,c}$ values

TPC Command Field in DCI format 0/3/4/6-0A	Accumulated $\delta_{PUSCH,c}$ [dB]	Absolute $\delta_{PUSCH,c}$ [dB] only DCI format 0/4/6-0A
0	-1	-4
1	0	-1
2	1	1
3	3	4

Table 5.1.1.1-3: Mapping of TPC Command Field in DCI format 3A to accumulated $\delta_{PUSCH,c}$ values

TPC Command Field in DCI format 3A	Accumulated $\delta_{PUSCH,c}$ [dB]
0	-1
1	1

If the UE is not configured with an SCG or a PUCCH-SCell, and if the total transmit power of the UE would exceed $\hat{P}_{CMAX}(i)$, the UE scales $\hat{P}_{PUSCH,c}(i)$ for the serving cell c in subframe i such that the condition

$$\sum_c w(i) \cdot \hat{P}_{PUSCH,c}(i) \leq (\hat{P}_{CMAX}(i) - \hat{P}_{PUCCH}(i))$$

is satisfied where $\hat{P}_{PUCCH}(i)$ is the linear value of $P_{PUCCH}(i)$, $\hat{P}_{PUSCH,c}(i)$ is the linear value of $P_{PUSCH,c}(i)$, $\hat{P}_{CMAX}(i)$ is the linear value of the UE total configured maximum output power P_{CMAX} defined in [6] in subframe i and $w(i)$ is a scaling factor of $\hat{P}_{PUSCH,c}(i)$ for serving cell c where $0 \leq w(i) \leq 1$. In case there is no PUCCH transmission in subframe i $\hat{P}_{PUCCH}(i) = 0$.

If the UE is not configured with an SCG or a PUCCH-SCell, and if the UE has PUSCH transmission with UCI on serving cell j and PUSCH without UCI in any of the remaining serving cells, and the total transmit power of the UE would exceed $\hat{P}_{CMAX}(i)$, the UE scales $\hat{P}_{PUSCH,c}(i)$ for the serving cells without UCI in subframe i such that the condition

$$\sum_{c \neq j} w(i) \cdot \hat{P}_{\text{PUSCH},c}(i) \leq (\hat{P}_{\text{CMAX}}(i) - \hat{P}_{\text{PUSCH},j}(i))$$

is satisfied where $\hat{P}_{\text{PUSCH},j}(i)$ is the PUSCH transmit power for the cell with UCI and $w(i)$ is a scaling factor of $\hat{P}_{\text{PUSCH},c}(i)$ for serving cell c without UCI. In this case, no power scaling is applied to $\hat{P}_{\text{PUSCH},j}(i)$ unless $\sum_{c \neq j} w(i) \cdot \hat{P}_{\text{PUSCH},c}(i) = 0$ and the total transmit power of the UE still would exceed $\hat{P}_{\text{CMAX}}(i)$.

For a UE not configured with a SCG or a PUCCH-SCell, note that $w(i)$ values are the same across serving cells when $w(i) > 0$ but for certain serving cells $w(i)$ may be zero.

If the UE is not configured with an SCG or a PUCCH-SCell, and if the UE has simultaneous PUCCH and PUSCH transmission with UCI on serving cell j and PUSCH transmission without UCI in any of the remaining serving cells, and the total transmit power of the UE would exceed $\hat{P}_{\text{CMAX}}(i)$, the UE obtains $\hat{P}_{\text{PUSCH},c}(i)$ according to

$$\hat{P}_{\text{PUSCH},j}(i) = \min(\hat{P}_{\text{PUSCH},j}(i), (\hat{P}_{\text{CMAX}}(i) - \hat{P}_{\text{PUCCH}}(i)))$$

and

$$\sum_{c \neq j} w(i) \cdot \hat{P}_{\text{PUSCH},c}(i) \leq (\hat{P}_{\text{CMAX}}(i) - \hat{P}_{\text{PUCCH}}(i) - \hat{P}_{\text{PUSCH},j}(i))$$

If the UE is not configured with a SCG or a PUCCH-SCell, and

- If the UE is configured with multiple TAGs, and if the PUCCH/PUSCH transmission of the UE on subframe i for a given serving cell in a TAG overlaps some portion of the first symbol of the PUSCH transmission on subframe $i+1$ for a different serving cell in another TAG the UE shall adjust its total transmission power to not exceed P_{CMAX} on any overlapped portion.
- If the UE is configured with multiple TAGs, and if the PUSCH transmission of the UE on subframe i for a given serving cell in a TAG overlaps some portion of the first symbol of the PUCCH transmission on subframe $i+1$ for a different serving cell in another TAG the UE shall adjust its total transmission power to not exceed P_{CMAX} on any overlapped portion.
- If the UE is configured with multiple TAGs, and if the SRS transmission of the UE in a symbol on subframe i for a given serving cell in a TAG overlaps with the PUCCH/PUSCH transmission on subframe i or subframe $i+1$ for a different serving cell in the same or another TAG the UE shall drop SRS if its total transmission power exceeds P_{CMAX} on any overlapped portion of the symbol.
- If the UE is configured with multiple TAGs and more than 2 serving cells, and if the SRS transmission of the UE in a symbol on subframe i for a given serving cell overlaps with the SRS transmission on subframe i for a different serving cell(s) and with PUSCH/PUCCH transmission on subframe i or subframe $i+1$ for another serving cell(s) the UE shall drop the SRS transmissions if the total transmission power exceeds P_{CMAX} on any overlapped portion of the symbol.
- If the UE is configured with multiple TAGs, the UE shall, when requested by higher layers, to transmit PRACH in a secondary serving cell in parallel with SRS transmission in a symbol on a subframe of a

different serving cell belonging to a different TAG, drop SRS if the total transmission power exceeds P_{MAX} on any overlapped portion in the symbol.

- If the UE is configured with multiple TAGs, the UE shall, when requested by higher layers, to transmit PRACH in a secondary serving cell in parallel with PUSCH/PUCCH in a different serving cell belonging to a different TAG, adjust the transmission power of PUSCH/PUCCH so that its total transmission power does not exceed P_{MAX} on the overlapped portion.

If the UE is configured with a LAA SCell for uplink transmissions, the UE may compute the scaling factor $w(i)$ assuming that the UE performs a PUSCH transmission on the LAA SCell in subframe i irrespective of whether the UE can access the LAA SCell for the PUSCH transmission in subframe i according to the channel access procedures described in subclause 15.2.1.

For a BL/CE UE configured with CEModeA, if the PUSCH is transmitted in more than one subframe $i_0, i_1, \dots, i_{N-1}$ where $i_0 < i_1 < \dots < i_{N-1}$, the PUSCH transmit power in subframe $i_k, k=0, 1, \dots, N-1$, is determined by

$$P_{PUSCH,c}(i_k) = P_{PUSCH,c}(i_0)$$

For a BL/CE UE configured with CEModeB, the PUSCH transmit power in subframe i_k is determined by

$$P_{PUSCH,c}(i_k) = P_{MAX,c}(i_0)$$

<...>

5.1.2 Physical uplink control channel

If the UE is configured with a SCG, the UE shall apply the procedures described in this subclause for both MCG and SCG.

- When the procedures are applied for MCG, the term ‘serving cell’ in this subclause refers to serving cell belonging to the MCG.

When the procedures are applied for SCG, the term ‘serving cell’ in this subclause refers to serving cell belonging to the SCG. The term ‘primary cell’ in this subclause refers to the PSCell of the SCG. If the UE is configured with a PUCCH-SCell, the UE shall apply the procedures described in this subclause for both primary PUCCH group and secondary PUCCH group.

- When the procedures are applied for the primary PUCCH group, the term ‘serving cell’ in this subclause refers to serving cell belonging to the primary PUCCH group.
- When the procedures are applied for the secondary PUCCH group, the term ‘serving cell’ in this subclause refers to serving cell belonging to the secondary PUCCH group. The term ‘primary cell’ in this subclause refers to the PUCCH-SCell of the secondary PUCCH group.

5.1.2.1 UE behaviour

If serving cell c is the primary cell, for PUCCH format 1/1a/1b/2/2a/2b/3, the setting of the UE Transmit power P_{PUCCH} for the physical uplink control channel (PUCCH) transmission in subframe i for serving cell c is defined by

$$P_{PUCCH}(i) = \min \left\{ P_{MAX,c}(i), P_{0_PUCCH} + PL_c + h(n_{CQI}, n_{HARQ}, n_{SR}) + \Delta_{F_PUCCH}(F) + \Delta_{TxD}(F') + g(i) \right\} \text{ [dBm]}$$

If serving cell c is the primary cell, for PUCCH format 4/5, the setting of the UE Transmit power P_{PUCCH} for the physical uplink control channel (PUCCH) transmission in subframe i for serving cell c is defined by

$$P_{\text{PUCCH}}(i) = \min \left\{ P_{\text{CMAX},c}(i), P_{0,\text{PUCCH}} + PL_c + 10 \log_{10}(M_{\text{PUCCH},c}(i)) + \Delta_{\text{TF},c}(i) + \Delta_{\text{F-PUCCH}}(F) + g(i) \right\} \text{ [dBm]}$$

If the UE is not transmitting PUCCH for the primary cell, for the accumulation of TPC command for PUCCH, the UE shall assume that the UE transmit power P_{PUCCH} for PUCCH in subframe i is computed by

$$P_{\text{PUCCH}}(i) = \min \{ P_{\text{CMAX},c}(i), P_{0,\text{PUCCH}} + PL_c + g(i) \} \text{ [dBm]}$$

where

- $P_{\text{CMAX},c}(i)$ is the configured UE transmit power defined in [6] in subframe i for serving cell c . If the UE transmits PUSCH without PUCCH in subframe i for the serving cell c , for the accumulation of TPC command for PUCCH, the UE shall assume $P_{\text{CMAX},c}(i)$ as given by subclause 5.1.1.1. If the UE does not transmit PUCCH and PUSCH in subframe i for the serving cell c , for the accumulation of TPC command for PUCCH, the UE shall compute $P_{\text{CMAX},c}(i)$ assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB and $\Delta T_c=0$ dB, where MPR, A-MPR, P-MPR and ΔT_c are defined in [6].
- The parameter $\Delta_{\text{F-PUCCH}}(F)$ is provided by higher layers. Each $\Delta_{\text{F-PUCCH}}(F)$ value corresponds to a PUCCH format (F) relative to PUCCH format 1a, where each PUCCH format (F) is defined in Table 5.4-1 of [3].
- If the UE is configured by higher layers to transmit PUCCH on two antenna ports, the value of $\Delta_{\text{TXD}}(F')$ is provided by higher layers where each PUCCH format F' is defined in Table 5.4-1 of [3]; otherwise, $\Delta_{\text{TXD}}(F') = 0$.
- $h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}})$ is a PUCCH format dependent value, where n_{CQI} corresponds to the number of information bits for the channel quality information defined in subclause 5.2.3.3 in [4]. $n_{\text{SR}} = 1$ if subframe i is configured for SR for the UE not having any associated transport block for UL-SCH, otherwise $n_{\text{SR}} = 0$. If the UE is configured with more than one serving cell, or the UE is configured with one serving cell and transmitting using PUCCH format 3, the value of n_{HARQ} is defined in subclause 10.1; otherwise, n_{HARQ} is the number of HARQ-ACK bits sent in subframe i .
 - For PUCCH format 1, 1a and 1b $h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}}) = 0$
 - For PUCCH format 1b with channel selection, if the UE is configured with more than one serving cell, $h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}}) = \frac{(n_{\text{HARQ}} - 1)}{2}$, otherwise, $h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}}) = 0$
 - For PUCCH format 2, 2a, 2b and normal cyclic prefix
$$h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}}) = \begin{cases} 10 \log_{10} \left(\frac{n_{\text{CQI}}}{4} \right) & \text{if } n_{\text{CQI}} \geq 4 \\ 0 & \text{otherwise} \end{cases}$$
 - For PUCCH format 2 and extended cyclic prefix
$$h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}}) = \begin{cases} 10 \log_{10} \left(\frac{n_{\text{CQI}} + n_{\text{HARQ}}}{4} \right) & \text{if } n_{\text{CQI}} + n_{\text{HARQ}} \geq 4 \\ 0 & \text{otherwise} \end{cases}$$
 - For PUCCH format 3 and when UE transmits HARQ-ACK/SR without periodic CSI,

- If the UE is configured by higher layers to transmit PUCCH format 3 on two antenna ports, or if the UE transmits more than 11 bits of HARQ-ACK/SR

$$h(n_{CQI}, n_{HARQ}, n_{SR}) = \frac{n_{HARQ} + n_{SR} - 1}{3}$$

- Otherwise

$$h(n_{CQI}, n_{HARQ}, n_{SR}) = \frac{n_{HARQ} + n_{SR} - 1}{2}$$

- For PUCCH format 3 and when UE transmits HARQ-ACK/SR and periodic CSI,
 - If the UE is configured by higher layers to transmit PUCCH format 3 on two antenna ports, or if the UE transmits more than 11 bits of HARQ-ACK/SR and CSI

$$h(n_{CQI}, n_{HARQ}, n_{SR}) = \frac{n_{HARQ} + n_{SR} + n_{CQI} - 1}{3}$$

- Otherwise

$$h(n_{CQI}, n_{HARQ}, n_{SR}) = \frac{n_{HARQ} + n_{SR} + n_{CQI} - 1}{2}$$

- For PUCCH format 4, $M_{PUCCH,c}(i)$ is the bandwidth of the PUCCH format 4 expressed in number of resource blocks valid for subframe i and serving cell c . For PUCCH format 5, $M_{PUCCH,c}(i) = 1$.

- $\Delta_{TF,c}(i) = 10 \log_{10}(2^{1.25 \cdot BP_{RE}(i)} - 1)$ where $BP_{RE}(i) = O_{UCI}(i) / N_{RE}(i)$,
 - $O_{UCI}(i)$ is the number of HARQ-ACK/SR/RI/CQI/PMI bits including CRC bits transmitted on PUCCH format 4/5 in subframe i ;
 - $N_{RE}(i) = M_{PUCCH,c}(i) \cdot N_{sc}^{RB} \cdot N_{symb}^{PUCCH}$ for PUCCH format 4 and $N_{RE}(i) = N_{sc}^{RB} \cdot N_{symb}^{PUCCH} / 2$ for PUCCH format 5;
 - $N_{symb}^{PUCCH} = 2 \cdot (N_{symb}^{UL} - 1) - 1$ if shortened PUCCH format 4 or shortened PUCCH format 5 is used in subframe i and $N_{symb}^{PUCCH} = 2 \cdot (N_{symb}^{UL} - 1)$ otherwise.

- P_{O_PUCCH} is a parameter composed of the sum of a parameter $P_{O_NOMINAL_PUCCH}$ provided by higher layers and a parameter $P_{O_UE_PUCCH}$ provided by higher layers.
- δ_{PUCCH} is a UE specific correction value, also referred to as a TPC command, included in a PDCCH with DCI format 1A/1B/1D/1/2A/2/2B/2C/2D for the primary cell, or included in a MPDCCH with DCI format 6-1A, or included in an EPDCCH with DCI format 1A/1B/1D/1/2A/2/2B/2C/2D for the primary cell, or sent jointly coded with other UE specific PUCCH correction values on a PDCCH/MPDCCH with DCI format 3/3A whose CRC parity bits are scrambled with TPC-PUCCH-RNTI.
 - For a non-BL/CE UE, if the UE is not configured for EPDCCH monitoring, the UE attempts to decode a PDCCH of DCI format 3/3A with the UE's TPC-PUCCH-RNTI and one or several PDCCHs of DCI format 1A/1B/1D/1/2A/2/2B/2C/2D with the UE's C-RNTI or SPS C-RNTI on every subframe except when in DRX.
 - If a UE is configured for EPDCCH monitoring, the UE attempts to decode

- a PDCCH of DCI format 3/3A with the UE's TPC-PUCCH-RNTI and one or several PDCCHs of DCI format 1A/1B/1D/1/2A/2/2B/2C/2D with the UE's C-RNTI or SPS C-RNTI as described in subclause 9.1.1, and
- one or several EPDCCHs of DCI format 1A/1B/1D/1/2A/2/2B/2C/2D with the UE's C-RNTI or SPS C-RNTI, as described in subclause 9.1.4.
- For a BL/CE UE configured with CEModeA, the UE attempts to decode a MPDCCH of DCI format 3/3A with the UE's TPC-PUCCH-RNTI and MPDCCH of DCI format 6-1A with the UE's C-RNTI or SPS C-RNTI on every BL/CE downlink subframe except when in DRX.
- If the UE decodes
 - a PDCCH with DCI format 1A/1B/1D/1/2A/2/2B/2C/2D or
 - an EPDCCH with DCI format 1A/1B/1D/1/2A/2/2B/2C/2D or
 - an MPDCCH with DCI format 6-1A

for the primary cell and the corresponding detected RNTI equals the C-RNTI or SPS C-RNTI of the UE and the TPC field in the DCI format is not used to determine the PUCCH resource as in subclause 10.1, the UE shall use the δ_{PUCCH} provided in that PDCCH/EPDCCH/MPDCCH.

Else

- if the UE decodes a PDCCH/MPDCCH with DCI format 3/3A, the UE shall use the δ_{PUCCH} provided in that PDCCH/MPDCCH
- else the UE shall set $\delta_{\text{PUCCH}} = 0$ dB.
- $g(i) = g(i-1) + \sum_{m=0}^{M-1} \delta_{\text{PUCCH}}(i-k_m)$ where $g(i)$ is the current PUCCH power control adjustment state and where $g(0)$ is the first value after reset.
- For FDD or FDD-TDD and primary cell frame structure type 1, $M = 1$ and $k_0 = 4$.
- For TDD, values of M and k_m are given in Table 10.1.3.1-1, where the "UL/DL configuration" in Table 10.1.3.1-1 corresponds to the *eimta-HARQ-ReferenceConfig-r12* for the primary cell when the UE is configured with the parameter *EIMTA-MainConfigServCell-r12* for the primary cell.
- The δ_{PUCCH} dB values signalled on PDCCH with DCI format 1A/1B/1D/1/2A/2/2B/2C/2D or EPDCCH with DCI format 1A/1B/1D/1/2A/2/2B/2C/2D or MPDCCH with DCI format 6-1A are given in Table 5.1.2.1-1. If the PDCCH with DCI format 1/1A/2/2A/2B/2C/2D or EPDCCH with DCI format 1/1A/2A/2/2B/2C/2D or MPDCCH with DCI format 6-1A is validated as an SPS activation PDCCH/EPDCCH/MPDCCH, or the PDCCH/EPDCCH with DCI format 1A or MPDCCH with DCI format 6-1A is validated as an SPS release PDCCH/EPDCCH/MPDCCH, then δ_{PUCCH} is 0dB.
- The δ_{PUCCH} dB values signalled on PDCCH/MPDCCH with DCI format 3/3A are given in Table 5.1.2.1-1 or in Table 5.1.2.1-2 as semi-statically configured by higher layers.
- If $P_{\text{O_UE_PUCCH}}$ value is changed by higher layers,
 - $g(0) = 0$

- Else
- $g(0) = \Delta P_{\text{rampup}} + \delta_{\text{msg } 2}$, where
 - $\delta_{\text{msg } 2}$ is the TPC command indicated in the random access response corresponding to the random access preamble transmitted in the primary cell, see subclause 6.2 and
 - if UE is transmitting PUCCH in subframe i ,

$$\Delta P_{\text{rampup}} = \min \left[\left\{ \max \left(0, P_{\text{CMAX},c} - \left(\begin{array}{c} P_{0_PUCCH} \\ + PL_c + h(n_{CQI}, n_{HARQ}, n_{SR}) \\ + \Delta_{F_PUCCH}(F) + \Delta_{TxD}(F') \end{array} \right) \right) \right\}, \Delta P_{\text{rampuprequested}} \right].$$

Otherwise,

$$\Delta P_{\text{rampup}} = \min \left[\left\{ \max(0, P_{\text{CMAX},c} - (P_{0_PUCCH} + PL_c)) \right\}, \Delta P_{\text{rampuprequested}} \right] \text{ and}$$

$\Delta P_{\text{rampuprequested}}$ is provided by higher layers and corresponds to the total power ramp-up requested by higher layers from the first to the last preamble in the primary cell.

- If UE has reached $P_{\text{CMAX},c}(i)$ for the primary cell, positive TPC commands for the primary cell shall not be accumulated.
- If UE has reached minimum power, negative TPC commands shall not be accumulated.
- UE shall reset accumulation
 - when $P_{\text{O_UE_PUCCH}}$ value is changed by higher layers
 - when the UE receives a random access response message for the primary cell
 - $g(i) = g(i-1)$ if i is not an uplink subframe in TDD or FDD-TDD and primary cell frame structure type 2.

For a BL/CE UE configured with CEModeA, if the PUCCH is transmitted in more than one subframe $i_0, i_1, \dots, i_{N-1}$ where $i_0 < i_1 < \dots < i_{N-1}$, the PUCCH transmit power in subframe $i_k, k=0, 1, \dots, N-1$ is determined by

$$P_{\text{PUCCH},c}(i_k) = P_{\text{PUCCH},c}(i_0)$$

For a BL/CE UE configured with CEModeB, the PUCCH transmit power in subframe i_k is determined by

$$P_{\text{PUCCH},c}(i_k) = P_{\text{CMAX},c}(i_0)$$

Table 5.1.2.1-1: Mapping of TPC Command Field in DCI format 1A/1B/1D/1/2A/2B/2C/2D/2/3/6-1A to δ_{PUCCH} values

TPC Command Field in DCI format 1A/1B/1D/1/2A/2B/2C/2D/2/3/6-1A	δ_{PUCCH} [dB]
0	-1
1	0
2	1
3	3

Table 5.1.2.1-2: Mapping of TPC Command Field in DCI format 3A to δ_{PUCCH} values

TPC Command Field in DCI format 3A	δ_{PUCCH} [dB]
0	-1
1	1

5.1.3 Sounding Reference Symbol (SRS)

5.1.3.1 UE behaviour

The setting of the UE Transmit power P_{SRS} for the SRS transmitted on subframe i for serving cell c is defined by

$$P_{\text{SRS},c}(i) = \min \left\{ P_{\text{CMAX},c}(i), P_{\text{SRS_OFFSET},c}(m) + 10 \log_{10}(M_{\text{SRS},c}) + P_{\text{O_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + f_c(i) \right\} \text{ [dBm]}$$

where

- $P_{\text{CMAX},c}(i)$ is the configured UE transmit power defined in [6] in subframe i for serving cell c .
- $P_{\text{SRS_OFFSET},c}(m)$ is semi-statically configured by higher layers for $m=0$ and $m=1$ for serving cell c . For SRS transmission given trigger type 0 then $m=0$ and for SRS transmission given trigger type 1 then $m=1$.
- $M_{\text{SRS},c}$ is the bandwidth of the SRS transmission in subframe i for serving cell c expressed in number of resource blocks.
- $f_c(i)$ is the current PUSCH power control adjustment state for serving cell c , see subclause 5.1.1.1.
- $P_{\text{O_PUSCH},c}(j)$ and $\alpha_c(j)$ are parameters as defined in subclause 5.1.1.1 for subframe i , where $j=1$.

If the UE is not configured with an SCG or a PUCCH-SCell, and if the total transmit power of the UE for the Sounding Reference Symbol in an SC-FDMA symbol would exceed $\hat{P}_{\text{CMAX}}(i)$, the UE scales $\hat{P}_{\text{SRS},c}(i)$ for the serving cell c and the SC-FDMA symbol in subframe i such that the condition

$$\sum_c w(i) \cdot \hat{P}_{\text{SRS},c}(i) \leq \hat{P}_{\text{CMAX}}(i)$$

is satisfied where $\hat{P}_{\text{SRS},c}(i)$ is the linear value of $P_{\text{SRS},c}(i)$, $\hat{P}_{\text{C}_{\text{MAX}}}(i)$ is the linear value of $P_{\text{C}_{\text{MAX}}}$ defined in [6] in subframe i and $w(i)$ is a scaling factor of $\hat{P}_{\text{SRS},c}(i)$ for serving cell c where $0 < w(i) \leq 1$. Note that $w(i)$ values are the same across serving cells.

If the UE is not configured with an SCG or a PUCCH-SCell, and if the UE is configured with multiple TAGs and the SRS transmission of the UE in an SC-FDMA symbol for a serving cell in subframe i in a TAG overlaps with the SRS transmission in another SC-FDMA symbol in subframe i for a serving cell in another TAG, and if the total transmit power of the UE for the Sounding Reference Symbol in the overlapped portion would exceed $\hat{P}_{\text{C}_{\text{MAX}}}(i)$, the UE scales $\hat{P}_{\text{SRS},c}(i)$ for the serving cell c and each of the overlapped SRS SC-FDMA symbols in subframe i such that the condition

$$\sum_c w(i) \cdot \hat{P}_{\text{SRS},c}(i) \leq \hat{P}_{\text{C}_{\text{MAX}}}(i)$$

is satisfied where $\hat{P}_{\text{SRS},c}(i)$ is the linear value of $P_{\text{SRS},c}(i)$, $\hat{P}_{\text{C}_{\text{MAX}}}(i)$ is the linear value of $P_{\text{C}_{\text{MAX}}}$ defined in [6] in subframe i and $w(i)$ is a scaling factor of $\hat{P}_{\text{SRS},c}(i)$ for serving cell c where $0 < w(i) \leq 1$. Note that $w(i)$ values are the same across serving cells.

If the UE is configured with a LAA SCell for uplink transmissions, the UE may compute the scaling factor $w(i)$ assuming that the UE performs a SRS transmission on the LAA SCell in subframe i irrespective of whether the UE can access the LAA SCell for the SRS transmission in subframe i according to the channel access procedures described in subclause 15.2.1.

If the UE is configured with higher layer parameter *UplinkPowerControlDedicated-v12x0* for serving cell c and if subframe i belongs to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12*, the UE shall use $f_{c,2}(i)$ instead of $f_c(i)$ to determine $P_{\text{SRS},c}(i)$ for subframe i and serving cell c , where $f_{c,2}(i)$ is defined in subclause 5.1.1.1.

Power headroom report is provided by the UE to the base station to allow base station realize how much extra transmission power is available in the UE and how to schedule resource to the UE properly, e.g. is it proper to schedule more resource to the UE (e.g. UE has more power headroom). A power headroom may be calculated from the difference between a current calculated transmission UE power (if there is transmission) and a maximum transmission power of the UE. In some circumstances, e.g. multiple carrier operation, it is also possible that a power headroom is reported while there is no current transmission, e.g. reporting power headroom for a carrier without ongoing transmission with another carrier. In such a case, a difference between a reference power (calculated based on some reference parameter(s)) and a UE maximum power is reported as power headroom, as known as virtual power headroom (PH). More details can be found in the following quotation from [5]:

5.1.1.2 Power headroom

There are two types of UE power headroom reports defined. A UE power headroom PH is valid for subframe i for serving cell c .

If the UE is configured with a SCG, and if the higher layer parameter *phr-ModeOtherCG-r12* for a CG indicates ‘virtual’, for power headroom reports transmitted on that CG, the UE shall compute PH assuming that it does not transmit PUSCH/PUCCH on any serving cell of the other CG.

If the UE is configured with a SCG,

- For computing power headroom for cells belonging to MCG, the term ‘serving cell’ in this subclause refers to serving cell belonging to the MCG.
- For computing power headroom for cells belonging to SCG, the term ‘serving cell’ in this subclause refers to serving cell belonging to the SCG. The term ‘primary cell’ in this subclause refers to the PSCell of the SCG.

If the UE is configured with a PUCCH-SCell,

- For computing power headroom for cells belonging to primary PUCCH group, the term ‘serving cell’ in this subclause refers to serving cell belonging to the primary PUCCH group.
- For computing power headroom for cells belonging to secondary PUCCH group, the term ‘serving cell’ in this subclause refers to serving cell belonging to the secondary PUCCH group. The term ‘primary cell’ in this subclause refers to the PUCCH-SCell of the secondary PUCCH group.

If the UE is configured with a LAA SCell for uplink transmissions, and the UE receives PDCCH/EPDCCH with DCI format 0A/0B/4A/4B corresponding to a PUSCH transmission on the LAA SCell in subframe i , power headroom for subframe i is computed assuming that the UE performs a PUSCH transmission on the LAA SCell in subframe i irrespective of whether the UE can access the LAA SCell for the PUSCH transmission in subframe i according to the channel access procedures described in subclause 15.2.1.

Type 1:

If the UE transmits PUSCH without PUCCH in subframe i for serving cell c , power headroom for a Type 1 report is computed using

$$PH_{\text{type1},c}(i) = P_{\text{CMAX},c}(i) - \left\{ 10 \log_{10}(M_{\text{PUSCH},c}(i)) + P_{\text{O_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + \Delta_{\text{TF},c}(i) + f_c(i) \right\} \text{ [dB]}$$

where, $P_{\text{CMAX},c}(i)$, $M_{\text{PUSCH},c}(i)$, $P_{\text{O_PUSCH},c}(j)$, $\alpha_c(j)$, PL_c , $\Delta_{\text{TF},c}(i)$ and $f_c(i)$ are defined in subclause 5.1.1.1.

If the UE transmits PUSCH with PUCCH in subframe i for serving cell c , power headroom for a Type 1 report is computed using

$$PH_{\text{type1},c}(i) = \tilde{P}_{\text{CMAX},c}(i) - \left\{ 10 \log_{10}(M_{\text{PUSCH},c}(i)) + P_{\text{O_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + \Delta_{\text{TF},c}(i) + f_c(i) \right\} \text{ [dB]}$$

where, $M_{\text{PUSCH},c}(i)$, $P_{\text{O_PUSCH},c}(j)$, $\alpha_c(j)$, PL_c , $\Delta_{\text{TF},c}(i)$ and $f_c(i)$ are defined in subclause

5.1.1.1. $\tilde{P}_{\text{CMAX},c}(i)$ is computed based on the requirements in [6] assuming a PUSCH only transmission in subframe i . For this case, the physical layer delivers $\tilde{P}_{\text{CMAX},c}(i)$ instead of $P_{\text{CMAX},c}(i)$ to higher layers.

If the UE does not transmit PUSCH in subframe i for serving cell c , power headroom for a Type 1 report is computed using

$$PH_{\text{type1},c}(i) = \tilde{P}_{\text{CMAX},c}(i) - \{P_{\text{O_PUSCH},c}(1) + \alpha_c(1) \cdot PL_c + f_c(i)\} \quad [\text{dB}]$$

where, $\tilde{P}_{\text{CMAX},c}(i)$ is computed assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB and ΔT_C =0dB, where MPR, A-MPR, P-MPR and ΔT_C are defined in [6]. $P_{\text{O_PUSCH},c}(1)$, $\alpha_c(1)$, PL_c , and $f_c(i)$ are defined in subclause 5.1.1.1.

Type 2:

If the UE transmits PUSCH simultaneous with PUCCH in subframe i for the primary cell, power headroom for a Type 2 report is computed using

$$PH_{\text{type2}}(i) = P_{\text{CMAX},c}(i) - 10 \log_{10} \left(\frac{10^{(10 \log_{10}(M_{\text{PUSCH},c}(i)) + P_{\text{O_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + \Delta_{\text{TF},c}(i) + f_c(i))/10}}{10^{(P_{\text{O_PUCCH}} + PL_c + h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}}) + \Delta_{\text{F_PUCCH}}(F) + \Delta_{\text{TxD}}(F') + g(i))/10}} \right) \quad [\text{dB}]$$

where, $P_{\text{CMAX},c}$, $M_{\text{PUSCH},c}(i)$, $P_{\text{O_PUSCH},c}(j)$, $\alpha_c(j)$, $\Delta_{\text{TF},c}(i)$ and $f_c(i)$ are the primary cell parameters as defined in subclause 5.1.1.1 and $P_{\text{O_PUCCH}}$, PL_c , $h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}})$, $\Delta_{\text{F_PUCCH}}(F)$, $\Delta_{\text{TxD}}(F')$ and $g(i)$ are defined in subclause 5.1.2.1

If the UE transmits PUSCH without PUCCH in subframe i for the primary cell, power headroom for a Type 2 report is computed using

$$PH_{\text{type2}}(i) = P_{\text{CMAX},c}(i) - 10 \log_{10} \left(\frac{10^{(10 \log_{10}(M_{\text{PUSCH},c}(i)) + P_{\text{O_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + \Delta_{\text{TF},c}(i) + f_c(i))/10}}{10^{(P_{\text{O_PUCCH}} + PL_c + g(i))/10}} \right) \quad [\text{dB}]$$

where, $P_{\text{CMAX},c}(i)$, $M_{\text{PUSCH},c}(i)$, $P_{\text{O_PUSCH},c}(j)$, $\alpha_c(j)$, $\Delta_{\text{TF},c}(i)$ and $f_c(i)$ are the primary cell parameters as defined in subclause 5.1.1.1 and $P_{\text{O_PUCCH}}$, PL_c and $g(i)$ are defined in subclause 5.1.2.1.

If the UE transmits PUCCH without PUSCH in subframe i for the primary cell, power headroom for a Type 2 report is computed using

$$PH_{\text{type2}}(i) = P_{\text{CMAX},c}(i) - 10 \log_{10} \left(\frac{10^{(P_{\text{O_PUSCH},c}(1) + \alpha_c(1) \cdot PL_c + f_c(i))/10}}{10^{(P_{\text{O_PUCCH}} + PL_c + h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}}) + \Delta_{\text{F_PUCCH}}(F) + \Delta_{\text{TxD}}(F') + g(i))/10}} \right) \quad [\text{dB}]$$

where, $P_{\text{O_PUSCH},c}(1)$, $\alpha_c(1)$ and $f_c(i)$ are the primary cell parameters as defined in subclause 5.1.1.1, $P_{\text{CMAX},c}(i)$, $P_{\text{O_PUCCH}}$, PL_c , $h(n_{\text{CQI}}, n_{\text{HARQ}}, n_{\text{SR}})$, $\Delta_{\text{F_PUCCH}}(F)$, $\Delta_{\text{TxD}}(F')$ and $g(i)$ are also defined in subclause 5.1.2.1.

If the UE does not transmit PUCCH or PUSCH in subframe i for the primary cell, power headroom for a Type 2 report is computed using

$$PH_{\text{type2}}(i) = \tilde{P}_{\text{CMAX},c}(i) - 10 \log_{10} \left(\frac{10^{(P_{\text{O_PUSCH},c}(1) + \alpha_c(1) \cdot PL_c + f_c(i))/10}}{+ 10^{(P_{\text{O_PUCCH}} + PL_c + g(i))/10}} \right) \text{ [dB]}$$

where, $\tilde{P}_{\text{CMAX},c}(i)$ is computed assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB and ΔT_C =0dB, where MPR, A-MPR, P-MPR and ΔT_C are defined in [6], $P_{\text{O_PUSCH},c}(1)$, $\alpha_c(1)$ and $f_c(i)$ are the primary cell parameters as defined in subclause 5.1.1.1 and $P_{\text{O_PUCCH}}$, PL_c and $g(i)$ are defined in subclause 5.1.2.1.

If the UE is unable to determine whether there is a PUCCH transmission corresponding to PDSCH transmission(s) or not, or which PUCCH resource is used, in subframe i for the primary cell, before generating power headroom for a Type 2 report, upon (E)PDCCH detection, with the following conditions:

- if both PUCCH format 1b with channel selection and *simultaneousPUCCH-PUSCH* are configured for the UE, or
- if PUCCH format 1b with channel selection is used for HARQ-ACK feedback for the UE configured with PUCCH format 3 and *simultaneousPUCCH-PUSCH* are configured,

then, UE is allowed to compute power headroom for a Type 2 using

$$PH_{\text{type2}}(i) = P_{\text{CMAX},c}(i) - 10 \log_{10} \left(\frac{10^{(10 \log_{10}(M_{\text{PUSCH},c}(i)) + P_{\text{O_PUSCH},c}(j) + \alpha_c(j) \cdot PL_c + \Delta_{\text{TF},c}(i) + f_c(i))/10}}{+ 10^{(P_{\text{O_PUCCH}} + PL_c + g(i))/10}} \right) \text{ [dB]}$$

where, $P_{\text{CMAX},c}(i)$, $M_{\text{PUSCH},c}(i)$, $P_{\text{O_PUSCH},c}(j)$, $\alpha_c(j)$, $\Delta_{\text{TF},c}(i)$ and $f_c(i)$ are the primary cell parameters as defined in subclause 5.1.1.1 and $P_{\text{O_PUCCH}}$, PL_c and $g(i)$ are defined in subclause 5.1.2.1.

The power headroom shall be rounded to the closest value in the range [40; -23] dB with steps of 1 dB and is delivered by the physical layer to higher layers.

If the UE is configured with higher layer parameter

UplinkPowerControlDedicated-v12x0 for serving cell c and if subframe i belongs to uplink power control subframe set 2 as indicated by the higher layer parameter *tpc-SubframeSet-r12*, the UE shall use $f_{c,2}(i)$ instead of $f_c(i)$ to

compute $PH_{\text{type1},c}(i)$ and $PH_{\text{type2},c}(i)$ for subframe i and serving cell c ,

where $f_{c,2}(i)$ is defined in subclause 5.1.1.1.

A UE maximum power mentioned above for power headroom derivation is determined by the capability of the UE and may also be controlled by the configuration of base station/cell. Also due to the linear range of power amplifier(PA) in UE's RF, the maximum power may be affected by the peak-to-average power ratio (PAPR) of the transmission. For example, if a transmission has a high PAPR, power back-off may be performed if the peak power would exceed the linear region when the average power is around the maximum power. A range of power back-off is allowed to balance the cost of UE PA and the UL transmission performance/coverage, which is known as maximum power reduction (MPR). Different modulation schemes (e.g. QPSK/16QAM) or different resource allocation (e.g. contiguous/non-contiguous or narrow band/ wide band resource allocation) would result in different PAPR, and thus may have different MPRs. More details may be found in the following quotation [6]:

6.2 Transmit power

6.2.1 Void

6.2.2 UE maximum output power

The following UE Power Classes define the maximum output power for any transmission bandwidth within the channel bandwidth for non CA configuration and UL-MIMO unless otherwise stated. The period of measurement shall be at least one sub frame (1ms).

Table 6.2.2-1: UE Power Class

EUTRA band	Class 1 (dBm)	Tolerance (dB)	Class 2 (dBm)	Tolerance (dB)	Class 3 (dBm)	Tolerance (dB)	Class 4 (dBm)	Tolerance (dB)
1					23	± 2		
2					23	$\pm 2^2$		
3					23	$\pm 2^2$		
4					23	± 2		
5					23	± 2		
6					23	± 2		
7					23	$\pm 2^2$		
8					23	$\pm 2^2$		
9					23	± 2		
10					23	± 2		
11					23	± 2		
12					23	$\pm 2^2$		
13					23	± 2		
14	31	$\pm 2/-3$			23	± 2		
17					23	± 2		
18					23	$\pm 2^5$		
19					23	± 2		
20					23	$\pm 2^2$		
21					23	± 2		
22					23	$\pm 2/-3.5^2$		
23					23 ⁵	$\pm 2^6$		
24					23	± 2		
25					23	$\pm 2^2$		
26					23	$\pm 2^2$		
27					23	± 2		
28					23	$\pm 2/-2.5$		
30					23	± 2		
31					23	± 2		
...								
33					23	± 2		
34					23	± 2		
35					23	± 2		
36					23	± 2		
37					23	± 2		
38					23	± 2		
39					23	± 2		
40					23	± 2		
41					23	$\pm 2^2$		
42					23	$\pm 2/-3$		
43					23	$\pm 2/-3$		
44					23	$\pm 2/[-3]$		
45					23	± 2		
...								
47					23	± 2		
65					23	± 2		
66					23	± 2		
68					23	± 2		
...								
70					23	± 2		
1. NOTE 1: Void 2. NOTE 2: ² refers to the transmission bandwidths (Figure 5.6-1) confined within F_{UL_low} and $F_{UL_low} + 4$ MHz or $F_{UL_high} - 4$ MHz and F_{UL_high}, the maximum output power requirement is relaxed by reducing the lower tolerance limit by 1.5 dB 3. NOTE 3: For the UE which supports both Band 11 and Band 21 operating frequencies, the tolerance is FFS.								

4. NOTE 4: $P_{\text{PowerClass}}$ is the maximum UE power specified without taking into account the tolerance
5. NOTE 5: For a UE that supports both Band 18 and Band 26, the maximum output power requirement is relaxed by reducing the lower tolerance limit by 1.5 dB for transmission bandwidths confined within 815 MHz and 818 MHz.
6. NOTE 6: When NS_20 is signalled, the total output power within 2000-2005 MHz shall be limited to 7 dBm.

<...>

6.2.3 UE maximum output power for modulation / channel bandwidth

For UE Power Class 1 and 3, the allowed Maximum Power Reduction (MPR) for the maximum output power in Table 6.2.2-1 due to higher order modulation and transmit bandwidth configuration (resource blocks) is specified in Table 6.2.3-1.

Table 6.2.3-1: Maximum Power Reduction (MPR) for Power Class 1 and 3

Modulation	Channel bandwidth / Transmission bandwidth (N_{RB})						MPR (dB)
	1.4 MHz	3.0 MHz	5 MHz	10 MHz	15 MHz	20 MHz	
QPSK	> 5	> 4	> 8	> 12	> 16	> 18	≤ 1
16 QAM	≤ 5	≤ 4	≤ 8	≤ 12	≤ 16	≤ 18	≤ 1
16 QAM	> 5	> 4	> 8	> 12	> 16	> 18	≤ 2
64 QAM	≤ 5	≤ 4	≤ 8	≤ 12	≤ 16	≤ 18	≤ 2
64 QAM	> 5	> 4	> 8	> 12	> 16	> 18	≤ 3

For PRACH, PUCCH and SRS transmissions, the allowed MPR is according to that specified for PUSCH QPSK modulation for the corresponding transmission bandwidth.

For each subframe, the MPR is evaluated per slot and given by the maximum value taken over the transmission(s) within the slot; the maximum MPR over the two slots is then applied for the entire subframe.

For transmissions with non-contiguous resource allocation in single component carrier, the allowed Maximum Power Reduction (MPR) for the maximum output power in table 6.2.2-1, is specified as follows

$$\text{MPR} = \text{CEIL} \{M_A, 0.5\}$$

Where M_A is defined as follows

$$M_A = \begin{cases} 8.00 - 10.12A & ; 0.00 < A \leq 0.33 \\ 5.67 - 3.07A & ; 0.33 < A \leq 0.77 \\ 3.31 & ; 0.77 < A \leq 1.00 \end{cases}$$

Where

$$A = N_{\text{RB_alloc}} / N_{\text{RB}}$$

$\text{CEIL}\{M_A, 0.5\}$ means rounding upwards to closest 0.5dB, i.e. $\text{MPR} \in [3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0]$

For the UE maximum output power modified by MPR, the power limits specified in subclause 6.2.5 apply.

<...>

6.2.3B UE maximum output power for modulation / channel bandwidth for UL-MIMO

For UE with two transmit antenna connectors in closed-loop spatial multiplexing scheme, the allowed Maximum Power Reduction (MPR) for the maximum output power in Table 6.2.2B-1 is specified in Table 6.2.3-1. The requirements shall be met with UL-MIMO configurations defined in Table 6.2.2B-2. For UE supporting UL-MIMO, the maximum output power is measured as the sum of the maximum output power at each UE antenna connector.

For the UE maximum output power modified by MPR, the power limits specified in subclause 6.2.5B apply.

If UE is configured for transmission on single-antenna port, the requirements in subclause 6.2.3 apply.

<...>

6.2.4 UE maximum output power with additional requirements

Additional ACLR and spectrum emission requirements can be signalled by the network to indicate that the UE shall also meet additional requirements in a specific deployment scenario. To meet these additional requirements, Additional Maximum Power Reduction (A-MPR) is allowed for the output power as specified in Table 6.2.2-1. Unless stated otherwise, an A-MPR of 0 dB shall be used.

For UE Power Class 1 and 3 the specific requirements and identified subclauses are specified in Table 6.2.4-1 along with the allowed A-MPR values that may be used to meet these requirements. The allowed A-MPR values specified below in Table 6.2.4.-1 to 6.2.4-15 are in addition to the allowed MPR requirements specified in subclause 6.2.3.

Table 6.2.4-1: Additional Maximum Power Reduction (A-MPR)

Network Signalling value	Requirements (subclause)	E-UTRA Band	Channel bandwidth (MHz)	Resources Blocks (N_{RB})	A-MPR (dB)
NS_01	6.6.2.1.1	Table 5.5-1	1.4, 3, 5, 10, 15, 20	Table 5.6-1	N/A
NS_03	6.6.2.2.1	2, 4, 10, 23, 25, 35, 36, 66, 70	3	>5	≤ 1
			5	>6	≤ 1
			10	>6	≤ 1
			15	>8	≤ 1
			20	>10	≤ 1
NS_04	6.6.2.2.2, 6.6.3.3.19	41	5, 10, 15, 20	Table 6.2.4-4	
NS_05	6.6.3.3.1	1	10, 15, 20	≥ 50 (NOTE1)	≤ 1 (NOTE1)
			15, 20	Table 6.2.4-18 (NOTE2)	
		65 (NOTE 3)	10, 15, 20	≥ 50	≤ 1 (NOTE 1)
			15, 20	Table 6.2.4-18 (NOTE 2)	
NS_06	6.6.2.2.3	12, 13, 14, 17	1.4, 3, 5, 10	Table 5.6-1	N/A
NS_07	6.6.2.2.3 6.6.3.3.2	13	10	Table 6.2.4-2	
NS_08	6.6.3.3.3	19	10, 15	> 44	≤ 3
NS_09	6.6.3.3.4	21	10, 15	> 40	≤ 1
				> 55	≤ 2
NS_10		20	15, 20	Table 6.2.4-3	
NS_11	6.6.2.2.1 6.6.3.3.13	23	1.4, 3, 5, 10, 15, 20	Table 6.2.4-5	
NS_12	6.6.3.3.5	26	1.4, 3, 5, 10, 15	Table 6.2.4-6	
NS_13	6.6.3.3.6	26	5	Table 6.2.4-7	
NS_14	6.6.3.3.7	26	10, 15	Table 6.2.4-8	
NS_15	6.6.3.3.8	26	1.4, 3, 5, 10, 15	Table 6.2.4-9 Table 6.2.4-10	
NS_16	6.6.3.3.9	27	3, 5, 10	Table 6.2.4-11, Table 6.2.4-12, Table 6.2.4-13	
NS_17	6.6.3.3.10	28	5, 10	Table 5.6-1	N/A
NS_18	6.6.3.3.11	28	5	≥ 2	≤ 1
			10, 15, 20	≥ 1	≤ 4
NS_19	6.6.3.3.12	44	10, 15, 20	Table 6.2.4-14	
NS_20	6.2.2 6.6.2.2.1 6.6.3.3.14	23	5, 10, 15, 20	Table 6.2.4-15	
NS_21	6.6.2.2.1 6.6.3.3.15	30	5, 10	Table 6.2.4-16	
NS_22	6.6.3.3.16	42, 43	5, 10, 15, 20	Table 6.2.4-17	
NS_23	6.6.3.3.17	42, 43	5, 10, 15, 20	N/A	
NS_24	6.6.3.3.20	65 (NOTE 4)	5, 10, 15, 20	Table 6.2.4-19	
NS_25	6.6.3.3.21	65 (NOTE 4)	5, 10, 15, 20	Table 6.2.4-20	
NS_26	6.6.3.3.22	68	5, 10, 15	Table 6.2.4-21	
...					
NS_32	-	-	-	-	-
7. NOTE 1 Applicable when the lower edge of the assigned E-UTRA UL channel bandwidth frequency is larger than or equal to the upper edge of PHS band (1915.7 MHz) + 4 MHz + the channel BW assigned, where channel BW is as defined in subclause 5.6. A-MPR for operations below this frequency is not covered in this version of specifications except for the channel assignments in NOTE2 as the emissions requirement in 6.6.3.3.1 may not be met. For 10MHz channel bandwidth whose carrier frequency is larger than or equal to 1945 MHz or 15 MHz channel bandwidth whose carrier frequency is larger than or equal to 1947.5 MHz, no A-MPR applies. 8. NOTE 2 Applicable when carrier frequency is 1932.5 MHz for 15MHz channel bandwidth or					

or 1930 MHz for 20MHz channel bandwidth case.

9. NOTE 3: Applicable when the E-UTRA carrier is within 1920-1980 MHz.
10. NOTE 4: Applicable when the upper edge of the channel bandwidth frequency is greater than 1980MHz.

<...>

6.2.5 Configured transmitted power

The UE is allowed to set its configured maximum output power $P_{\text{CMAX},c}$ for serving cell c . The configured maximum output power $P_{\text{CMAX},c}$ is set within the following bounds:

$P_{\text{CMAX}_L,c} \leq P_{\text{CMAX},c} \leq P_{\text{CMAX}_H,c}$ with

$$P_{\text{CMAX}_L,c} = \text{MIN} \{ P_{\text{EMAX},c} - \Delta T_{C,c}, P_{\text{PowerClass}} - \text{MAX}(\text{MPR}_c + \text{A-MPR}_c + \Delta T_{\text{IB},c} + \Delta T_{C,c} + \Delta T_{\text{ProSe}}, \text{P-MPR}_c) \}$$

$$P_{\text{CMAX}_H,c} = \text{MIN} \{ P_{\text{EMAX},c}, P_{\text{PowerClass}} \}$$

where

- $P_{\text{EMAX},c}$ is the value given by IE $P\text{-Max}$ for serving cell c , defined in [7];
- $P_{\text{PowerClass}}$ is the maximum UE power specified in Table 6.2.2-1 without taking into account the tolerance specified in the Table 6.2.2-1;
- MPR_c and A-MPR_c for serving cell c are specified in subclause 6.2.3 and subclause 6.2.4, respectively;
- $\Delta T_{\text{IB},c}$ is the additional tolerance for serving cell c as specified in Table 6.2.5-2; $\Delta T_{\text{IB},c} = 0$ dB otherwise;
- $\Delta T_{C,c} = 1.5$ dB when NOTE 2 in Table 6.2.2-1 applies;
- $\Delta T_{C,c} = 0$ dB when NOTE 2 in Table 6.2.2-1 does not apply;
- $\Delta T_{\text{ProSe}} = 0.1$ dB when the UE supports ProSe Direct Discovery and/or ProSe Direct Communication on the corresponding E-UTRA ProSe band; $\Delta T_{\text{ProSe}} = 0$ dB otherwise.

P-MPR_c is the allowed maximum output power reduction for

- a) ensuring compliance with applicable electromagnetic energy absorption requirements and addressing unwanted emissions / self desense requirements in case of simultaneous transmissions on multiple RAT(s) for scenarios not in scope of 3GPP RAN specifications;
- b) ensuring compliance with applicable electromagnetic energy absorption requirements in case of proximity detection is used to address such requirements that require a lower maximum output power.

The UE shall apply P-MPR_c for serving cell c only for the above cases. For UE conducted conformance testing P-MPR shall be 0 dB

NOTE 1: P-MPR_c was introduced in the $P_{\text{CMAX},c}$ equation such that the UE can report to the eNB the available maximum output transmit power. This information can be used by the eNB for scheduling decisions.

NOTE 2: P-MPR_c may impact the maximum uplink performance for the selected UL transmission path.

For each subframe, the $P_{\text{CMAX_L},c}$ for serving cell c is evaluated per slot and given by the minimum value taken over the transmission(s) within the slot; the minimum $P_{\text{CMAX_L},c}$ over the two slots is then applied for the entire subframe. $P_{\text{PowerClass}}$ shall not be exceeded by the UE during any period of time.

The measured configured maximum output power $P_{\text{UMAX},c}$ shall be within the following bounds:

$$P_{\text{CMAX_L},c} - \text{MAX}\{T_{\text{L},c}, T(P_{\text{CMAX_L},c})\} \leq P_{\text{UMAX},c} \leq P_{\text{CMAX_H},c} + T(P_{\text{CMAX_H},c}).$$

where the tolerance $T(P_{\text{CMAX},c})$ for applicable values of $P_{\text{CMAX},c}$ is specified in Table 6.2.5-1, and Table 6.2.5-1A. The tolerance $T_{\text{L},c}$ is the absolute value of the lower tolerance for the applicable operating band as specified in Table 6.2.2-1.

Table 6.2.5-1: P_{CMAX} tolerance

$P_{\text{CMAX},c}$ (dBm)	Tolerance $T(P_{\text{CMAX},c})$ (dB)
$23 < P_{\text{CMAX},c} \leq 33$	2.0
$21 \leq P_{\text{CMAX},c} \leq 23$	2.0
$20 \leq P_{\text{CMAX},c} < 21$	2.5
$19 \leq P_{\text{CMAX},c} < 20$	3.5
$18 \leq P_{\text{CMAX},c} < 19$	4.0
$13 \leq P_{\text{CMAX},c} < 18$	5.0
$8 \leq P_{\text{CMAX},c} < 13$	6.0
$-40 \leq P_{\text{CMAX},c} < 8$	7.0

Table 6.2.5-1A: P_{CMAX} tolerance for power class 5

$P_{\text{CMAX},c}$ (dBm)	Tolerance $T(P_{\text{CMAX},c})$ (dB)
$P_{\text{CMAX},c} = 20$	2.0
$19 \leq P_{\text{CMAX},c} < 20$	3.5
$18 \leq P_{\text{CMAX},c} < 19$	4.0
$13 \leq P_{\text{CMAX},c} < 18$	5.0
$8 \leq P_{\text{CMAX},c} < 13$	6.0
$-40 \leq P_{\text{CMAX},c} < 8$	7.0

For the UE which supports inter-band carrier aggregation configurations with the uplink assigned to one or two E-UTRA bands the $\Delta T_{\text{IB},c}$ is defined for applicable bands in Table 6.2.5-2, Table 6.2.5-3 and Table 6.2.5-4.

<...>

6.2.5A Configured transmitted power for CA

For uplink carrier aggregation the UE is allowed to set its configured maximum output power $P_{\text{CMAX},c}$ for serving cell c and its total configured maximum output power P_{CMAX} .

The configured maximum output power $P_{\text{CMAX},c}$ on serving cell c shall be set as specified in subclause 6.2.5.

For uplink inter-band carrier aggregation, MPR_c and A-MPR_c apply per serving cell c and are specified in subclause 6.2.3 and subclause 6.2.4, respectively. P-MPR_c accounts for power management for serving cell c . $P_{\text{CMAX},c}$ is calculated under the assumption that the transmit power is increased independently on all component carriers.

For uplink intra-band contiguous and non-contiguous carrier aggregation, $MPR_c = MPR$ and $A-MPR_c = A-MPR$ with MPR and $A-MPR$ specified in subclause 6.2.3A and subclause 6.2.4A respectively. There is one power management term for the UE, denoted $P-MPR$, and $P-MPR_c = P-MPR$. $P_{CMAX,c}$ is calculated under the assumption that the transmit power is increased by the same amount in dB on all component carriers.

The total configured maximum output power P_{CMAX} shall be set within the following bounds:

$$P_{CMAX_L} \leq P_{CMAX} \leq P_{CMAX_H}$$

For uplink inter-band carrier aggregation with one serving cell c per operating band,

$$P_{CMAX_L} = \min \{ 10 \log_{10} \sum \min [p_{EMAX,c} / (\Delta t_{C,c}), p_{PowerClass} / (mpr_c \cdot a-mpr_c \cdot \Delta t_{C,c} \cdot \Delta t_{IB,c} \cdot \Delta t_{ProSe}) , p_{PowerClass} / pmpr_c], P_{PowerClass} \}$$

$$P_{CMAX_H} = \min \{ 10 \log_{10} \sum p_{EMAX,c} , P_{PowerClass} \}$$

where

- $p_{EMAX,c}$ is the linear value of $P_{EMAX,c}$ which is given by IE *P-Max* for serving cell c in [7];
- $P_{PowerClass}$ is the maximum UE power specified in Table 6.2.2A-1 without taking into account the tolerance specified in the Table 6.2.2A-1; $p_{PowerClass}$ is the linear value of $P_{PowerClass}$;
- mpr_c and $a-mpr_c$ are the linear values of MPR_c and $A-MPR_c$ as specified in subclause 6.2.3 and subclause 6.2.4, respectively;
- $pmpr_c$ is the linear value of $P-MPR_c$;
- $\Delta t_{C,c}$ is the linear value of $\Delta T_{C,c}$. $\Delta t_{C,c} = 1.41$ when NOTE 2 in Table 6.2.2-1 applies for a serving cell c , otherwise $\Delta t_{C,c} = 1$;
- $\Delta t_{IB,c}$ is the linear value of the inter-band relaxation term $\Delta T_{IB,c}$ of the serving cell c as specified in Table 6.2.5-2; otherwise $\Delta t_{IB,c} = 1$;
- Δt_{ProSe} is the linear value of ΔT_{ProSe} and applies as specified in subclause 6.2.5.

For uplink intra-band contiguous and non-contiguous carrier aggregation,

$$P_{CMAX_L} = \min \{ 10 \log_{10} \sum p_{EMAX,c} - \Delta T_C , P_{PowerClass} - \max(MPR + A-MPR + \Delta T_{IB,c} + \Delta T_C + \Delta T_{ProSe}, P-MPR) \}$$

$$P_{CMAX_H} = \min \{ 10 \log_{10} \sum p_{EMAX,c} , P_{PowerClass} \}$$

where

- $p_{EMAX,c}$ is the linear value of $P_{EMAX,c}$ which is given by IE *P-Max* for serving cell c in [7];
- $P_{PowerClass}$ is the maximum UE power specified in Table 6.2.2A-1 without taking into account the tolerance specified in the Table 6.2.2A-1;
- MPR and $A-MPR$ are specified in subclause 6.2.3A and subclause 6.2.4A respectively;
- $\Delta T_{IB,c}$ is the additional tolerance for serving cell c as specified in Table 6.2.5-2;
- $P-MPR$ is the power management term for the UE;
- ΔT_C is the highest value $\Delta T_{C,c}$ among all serving cells c in the subframe over both timeslots. $\Delta T_{C,c} = 1.5$ dB when NOTE 2 in Table 6.2.2A-1 applies to the serving cell c , otherwise $\Delta T_{C,c} = 0$ dB;
- ΔT_{ProSe} applies as specified in subclause 6.2.5.

For combinations of intra-band and inter-band carrier aggregation with UE configured for transmission on three serving cells (up to two contiguously aggregated carriers per operating band),

$$P_{\text{CMAX_L}} = \text{MIN} \{ 10 \log_{10} \sum (p_{\text{CMAX_L}, B_i}), P_{\text{PowerClass}} \}$$

$$P_{\text{CMAX_H}} = \text{MIN} \{ 10 \log_{10} \sum p_{\text{EMAX}, c}, P_{\text{PowerClass}} \}$$

where

- $p_{\text{EMAX}, c}$ is the linear value of $P_{\text{EMAX}, c}$ which is given by IE *P-Max* for serving cell c in [7];
- $P_{\text{PowerClass}}$ is the maximum UE power specified in Table 6.2.2A-0 without taking into account the tolerance specified in the Table 6.2.2A-0; $p_{\text{PowerClass}}$ is the linear value of $P_{\text{PowerClass}}$;
- $p_{\text{CMAX_L}, B_i}$ is the linear values of $P_{\text{CMAX_L}}$ as specified in corresponding operating band. $P_{\text{CMAX_L}, c}$ specified for single carrier in subclause 6.2.5 applies for operating band supporting one serving cell. $P_{\text{CMAX_L}}$ specified for uplink intra-band contiguous carrier aggregation in subclause 6.2.5A applies for operating band supporting two contiguous serving cells.

For each subframe, the $P_{\text{CMAX_L}}$ is evaluated per slot and given by the minimum value taken over the transmission(s) within the slot; the minimum $P_{\text{CMAX_L}}$ over the two slots is then applied for the entire subframe. $P_{\text{PowerClass}}$ shall not be exceeded by the UE during any period of time.

If the UE is configured with multiple TAGs and transmissions of the UE on subframe i for any serving cell in one TAG overlap some portion of the first symbol of the transmission on subframe $i + 1$ for a different serving cell in another TAG, the UE minimum of $P_{\text{CMAX_L}}$ for subframes i and $i + 1$ applies for any overlapping portion of subframes i and $i + 1$. $P_{\text{PowerClass}}$ shall not be exceeded by the UE during any period of time.

The measured maximum output power P_{UMAX} over all serving cells shall be within the following range:

$$P_{\text{CMAX_L}} - \text{MAX} \{ T_L, T_{\text{LOW}}(P_{\text{CMAX_L}}) \} \leq P_{\text{UMAX}} \leq P_{\text{CMAX_H}} + T_{\text{HIGH}}(P_{\text{CMAX_H}})$$

$$P_{\text{UMAX}} = 10 \log_{10} \sum p_{\text{UMAX}, c}$$

where $p_{\text{UMAX}, c}$ denotes the measured maximum output power for serving cell c expressed in linear scale. The tolerances $T_{\text{LOW}}(P_{\text{CMAX}})$ and $T_{\text{HIGH}}(P_{\text{CMAX}})$ for applicable values of P_{CMAX} are specified in Table 6.2.5A-1 and Table 6.2.5A-2 for inter-band carrier aggregation and intra-band carrier aggregation, respectively. The tolerance T_L is the absolute value of the lower tolerance for applicable E-UTRA CA configuration as specified in Table 6.2.2A-0, Table 6.2.2A-1 and Table 6.2.2A-2 for inter-band carrier aggregation, intra-band contiguous carrier aggregation and intra-band non-contiguous carrier aggregation, respectively.

Table 6.2.5A-1: P_{CMAX} tolerance for uplink inter-band CA (two bands)

P_{CMAX} (dBm)	Tolerance $T_{\text{LOW}}(P_{\text{CMAX}})$ (dB)	Tolerance $T_{\text{HIGH}}(P_{\text{CMAX}})$ (dB)
$P_{\text{CMAX}} = 23$	3.0	2.0
$22 \leq P_{\text{CMAX}} < 23$	5.0	2.0
$21 \leq P_{\text{CMAX}} < 22$	5.0	3.0
$20 \leq P_{\text{CMAX}} < 21$	6.0	4.0
$16 \leq P_{\text{CMAX}} < 20$	5.0	
$11 \leq P_{\text{CMAX}} < 16$	6.0	
$-40 \leq P_{\text{CMAX}} < 11$	7.0	

Table 6.2.5A-2: P_{CMAX} tolerance

P_{CMAX} (dBm)	Tolerance $T_{\text{LOW}}(P_{\text{CMAX}})$ (dB)	Tolerance $T_{\text{HIGH}}(P_{\text{CMAX}})$ (dB)
$21 \leq P_{\text{CMAX}} \leq 23$	2.0	
$20 \leq P_{\text{CMAX}} < 21$	2.5	
$19 \leq P_{\text{CMAX}} < 20$	3.5	
$18 \leq P_{\text{CMAX}} < 19$	4.0	
$13 \leq P_{\text{CMAX}} < 18$	5.0	
$8 \leq P_{\text{CMAX}} < 13$	6.0	
$-40 \leq P_{\text{CMAX}} < 8$	7.0	

6.2.5B Configured transmitted power for UL-MIMO

For UE supporting UL-MIMO, the transmitted power is configured per each UE.

The definitions of configured maximum output power $P_{\text{CMAX},c}$, the lower bound $P_{\text{CMAX}_L,c}$, and the higher bound $P_{\text{CMAX}_H,c}$ specified in subclause 6.2.5 shall apply to UE supporting UL-MIMO, where

- $P_{\text{PowerClass}}$ and $\Delta T_{C,c}$ are specified in subclause 6.2.2B;
- MPR_c is specified in subclause 6.2.3B;
- A-MPR_c is specified in subclause 6.2.4B.

The measured configured maximum output power $P_{\text{UMAX},c}$ for serving cell c shall be within the following bounds:

$$P_{\text{CMAX}_L,c} - \text{MAX}\{T_L, T_{\text{LOW}}(P_{\text{CMAX}_L,c})\} \leq P_{\text{UMAX},c} \leq P_{\text{CMAX}_H,c} + T_{\text{HIGH}}(P_{\text{CMAX}_H,c})$$

where $T_{\text{LOW}}(P_{\text{CMAX}_L,c})$ and $T_{\text{HIGH}}(P_{\text{CMAX}_H,c})$ are defined as the tolerance and applies to $P_{\text{CMAX}_L,c}$ and $P_{\text{CMAX}_H,c}$ separately, while T_L is the absolute value of the lower tolerance in Table 6.2.2B-1 for the applicable operating band.

For UE with two transmit antenna connectors in closed-loop spatial multiplexing scheme, the tolerance is specified in Table 6.2.5B-1. The requirements shall be met with UL-MIMO configurations specified in Table 6.2.2B-2.

Table 6.2.5B-1: $P_{\text{CMAX},c}$ tolerance in closed-loop spatial multiplexing scheme

$P_{\text{CMAX},c}$ (dBm)	Tolerance $T_{\text{LOW}}(P_{\text{CMAX},L,c})$ (dB)	Tolerance $T_{\text{HIGH}}(P_{\text{CMAX},H,c})$ (dB)
$P_{\text{CMAX},c} = 23$	3.0	2.0
$22 \leq P_{\text{CMAX},c} < 23$	5.0	2.0
$21 \leq P_{\text{CMAX},c} < 22$	5.0	3.0
$20 \leq P_{\text{CMAX},c} < 21$	6.0	4.0
$16 \leq P_{\text{CMAX},c} < 20$	5.0	
$11 \leq P_{\text{CMAX},c} < 16$	6.0	
$-40 \leq P_{\text{CMAX},c} < 11$	7.0	

If UE is configured for transmission on single-antenna port, the requirements in subclause 6.2.5 apply.

Also, to avoid excessive reporting of power headroom, power headroom report would be triggered under some conditions, e.g. when the pathloss/power headroom value change a lot or the previously reporting is too far from now, e.g. a timer has expired since last report. More detail description can be found in below quotation [7]:

5.4.3 Multiplexing and assembly

5.4.3.1 Logical channel prioritization

The Logical Channel Prioritization procedure is applied when a new transmission is performed.

RRC controls the scheduling of uplink data by signalling for each logical channel: *priority* where an increasing *priority* value indicates a lower priority level, *prioritisedBitRate* which sets the Prioritized Bit Rate (PBR), *bucketSizeDuration* which sets the Bucket Size Duration (BSD). For NB-IoT, *prioritisedBitRate*, *bucketSizeDuration* and the corresponding steps of the Logical Channel Prioritisation procedure (i.e., Step 1 and Step 2 below) are not applicable.

The MAC entity shall maintain a variable B_j for each logical channel j . B_j shall be initialized to zero when the related logical channel is established, and incremented by the product $\text{PBR} \times \text{TTI duration}$ for each TTI, where PBR is Prioritized Bit Rate of logical channel j . However, the value of B_j can never exceed the bucket size and if the value of B_j is larger than the bucket size of logical channel j , it shall be set to the bucket size. The bucket size of a logical channel is equal to $\text{PBR} \times \text{BSD}$, where PBR and BSD are configured by upper layers.

The MAC entity shall perform the following Logical Channel Prioritization procedure when a new transmission is performed:

- The MAC entity shall allocate resources to the logical channels in the following steps:
 - Step 1: All the logical channels with $B_j > 0$ are allocated resources in a decreasing priority order. If the PBR of a logical channel is set to “infinity”, the MAC entity shall allocate resources for all the data that is available for transmission on the logical channel before meeting the PBR of the lower priority logical channel(s);
 - Step 2: the MAC entity shall decrement B_j by the total size of MAC SDUs served to logical channel j in Step 1;
- NOTE: The value of B_j can be negative.
- Step 3: if any resources remain, all the logical channels are served in a strict decreasing priority order (regardless of the value of B_j) until either the data for that logical channel or the UL grant is

exhausted, whichever comes first. Logical channels configured with equal priority should be served equally.

- The UE shall also follow the rules below during the scheduling procedures above:
 - the UE should not segment an RLC SDU (or partially transmitted SDU or retransmitted RLC PDU) if the whole SDU (or partially transmitted SDU or retransmitted RLC PDU) fits into the remaining resources of the associated MAC entity;
 - if the UE segments an RLC SDU from the logical channel, it shall maximize the size of the segment to fill the grant of the associated MAC entity as much as possible;
 - the UE should maximise the transmission of data.
 - if the MAC entity is given an UL grant size that is equal to or larger than 4 bytes while having data available for transmission, the MAC entity shall not transmit only padding BSR and/or padding (unless the UL grant size is less than 7 bytes and an AMD PDU segment needs to be transmitted);
 - for transmissions on serving cells operating according to Frame Structure Type 3, the MAC entity shall only consider logical channels for which *laa-Allowed* has been configured.

The MAC entity shall not transmit data for a logical channel corresponding to a radio bearer that is suspended (the conditions for when a radio bearer is considered suspended are defined in [8]).

If the MAC PDU includes only the MAC CE for padding BSR or periodic BSR with zero MAC SDUs and there is no aperiodic CSI requested for this TTI [2], the MAC entity shall not generate a MAC PDU for the HARQ entity in the following cases:

- in case the MAC entity is configured with *skipUplinkTxDynamic* and the grant indicated to the HARQ entity was addressed to a C-RNTI; or
- in case the MAC entity is configured with *skipUplinkTxSPS* and the grant indicated to the HARQ entity is a configured uplink grant;

For the Logical Channel Prioritization procedure, the MAC entity shall take into account the following relative priority in decreasing order:

- MAC control element for C-RNTI or data from UL-CCCH;
 - MAC control element for SPS confirmation;
 - MAC control element for BSR, with exception of BSR included for padding;
 - MAC control element for PHR, Extended PHR, or Dual Connectivity PHR;
 - MAC control element for Sidelink BSR, with exception of Sidelink BSR included for padding;
 - data from any Logical Channel, except data from UL-CCCH;
 - MAC control element for BSR included for padding;
 - MAC control element for Sidelink BSR included for padding.
- NOTE: When the MAC entity is requested to transmit multiple MAC PDUs in one TTI, steps 1 to 3 and the associated rules may be applied either to each grant independently or to the sum of the capacities of the grants. Also the order in which the grants are processed is left up to UE implementation. It is up to the UE implementation to decide in which MAC PDU a MAC control element is included when MAC entity is requested to transmit multiple MAC PDUs in one TTI. When the UE is requested to generate MAC PDU(s) in two MAC entities in one TTI, it is up to UE implementation in which order the grants are processed.

<...>

5.4.6 Power Headroom Reporting

The Power Headroom reporting procedure is used to provide the serving eNB with information about the difference between the nominal UE maximum transmit power and the estimated power for UL-SCH transmission per activated Serving Cell and also with information about the difference between the nominal UE maximum power and the estimated power for UL-SCH and PUCCH transmission on SpCell and PUCCH SCell.

The reporting period, delay and mapping of Power Headroom are defined in subclause 9.1.8 of [9]. RRC controls Power Headroom reporting by configuring the two timers *periodicPHR-Timer* and *prohibitPHR-Timer*, and by signalling *dl-PathlossChange* which sets the change in measured downlink pathloss and the required power backoff due to power management (as allowed by $P\text{-MPR}_c$ [10]) to trigger a PHR [8].

A Power Headroom Report (PHR) shall be triggered if any of the following events occur:

- *prohibitPHR-Timer* expires or has expired and the path loss has changed more than *dl-PathlossChange* dB for at least one activated Serving Cell of any MAC entity which is used as a pathloss reference since the last transmission of a PHR in this MAC entity when the MAC entity has UL resources for new transmission;
- *periodicPHR-Timer* expires;
- upon configuration or reconfiguration of the power headroom reporting functionality by upper layers [8], which is not used to disable the function;
- activation of an SCell of any MAC entity with configured uplink;
- addition of the PSCell;
- *prohibitPHR-Timer* expires or has expired, when the MAC entity has UL resources for new transmission, and the following is true in this TTI for any of the activated Serving Cells of any MAC entity with configured uplink:
 - there are UL resources allocated for transmission or there is a PUCCH transmission on this cell, and the required power backoff due to power management (as allowed by $P\text{-MPR}_c$ [10]) for this cell has changed more than *dl-PathlossChange* dB since the last transmission of a PHR when the MAC entity had UL resources allocated for transmission or PUCCH transmission on this cell.

NOTE: The MAC entity should avoid triggering a PHR when the required power backoff due to power management decreases only temporarily (e.g. for up to a few tens of milliseconds) and it should avoid reflecting such temporary decrease in the values of $P_{\text{CMAX},c}/\text{PH}$ when a PHR is triggered by other triggering conditions.

If the MAC entity has UL resources allocated for new transmission for this TTI the MAC entity shall:

- if it is the first UL resource allocated for a new transmission since the last MAC reset, start *periodicPHR-Timer*;
- if the Power Headroom reporting procedure determines that at least one PHR has been triggered and not cancelled, and;

- if the allocated UL resources can accommodate the MAC control element for PHR which the MAC entity is configured to transmit, plus its subheader, as a result of logical channel prioritization:
 - if *extendedPHR* is configured:
 - for each activated Serving Cell with configured uplink:
 - obtain the value of the Type 1 power headroom;
 - if the MAC entity has UL resources allocated for transmission on this Serving Cell for this TTI:
 - obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer;
 - if *simultaneousPUCCH-PUSCH* is configured:
 - obtain the value of the Type 2 power headroom for the PCell;
 - obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer (see subclause 5.1.1.2 of [2]);
 - instruct the Multiplexing and Assembly procedure to generate and transmit an Extended PHR MAC control element for *extendedPHR* as defined in subclause 6.1.3.6a based on the values reported by the physical layer;
 - else if *extendedPHR2* is configured:
 - for each activated Serving Cell with configured uplink:
 - obtain the value of the Type 1 power headroom;
 - if the MAC entity has UL resources allocated for transmission on this Serving Cell for this TTI:
 - obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer;
 - if a PUCCH SCell is configured and activated:
 - obtain the value of the Type 2 power headroom for the PCell and PUCCH SCell;
 - obtain the values for the corresponding $P_{\text{CMAX},c}$ fields from the physical layer (see subclause 5.1.1.2 of [2]);
 - else:
 - if *simultaneousPUCCH-PUSCH* is configured for the PCell:
 - obtain the value of the Type 2 power headroom for the PCell;
 - obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer (see subclause 5.1.1.2 of [2]);
 - instruct the Multiplexing and Assembly procedure to generate and transmit an Extended PHR MAC control element for *extendedPHR2* according to configured *ServCellIndex* and the PUCCH(s) for the MAC entity as defined in subclause 6.1.3.6a based on the values reported by the physical layer;
 - else if *dualConnectivityPHR* is configured:
 - for each activated Serving Cell with configured uplink associated with any MAC entity:
 - obtain the value of the Type 1 power headroom;

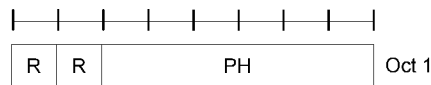
- if this MAC entity has UL resources allocated for transmission on this Serving Cell for this TTI or if the other MAC entity has UL resources allocated for transmission on this Serving Cell for this TTI and *phr-ModeOtherCG* is set to *real* by upper layers:
 - obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer;
- if *simultaneousPUCCH-PUSCH* is configured:
 - obtain the value of the Type 2 power headroom for the SpCell;
 - obtain the value for the corresponding $P_{\text{CMAX},c}$ field for the SpCell from the physical layer (see subclause 5.1.1.2 of [2]);
- obtain the value of the Type 2 power headroom for the SpCell of the other MAC entity;
- if *phr-ModeOtherCG* is set to *real* by upper layers:
 - obtain the value for the corresponding $P_{\text{CMAX},c}$ field for the SpCell of the other MAC entity from the physical layer (see subclause 5.1.1.2 of [2]);
- instruct the Multiplexing and Assembly procedure to generate and transmit a Dual Connectivity PHR MAC control element as defined in subclause 6.1.3.6b based on the values reported by the physical layer;
- else:
 - obtain the value of the Type 1 power headroom from the physical layer;
 - instruct the Multiplexing and Assembly procedure to generate and transmit a PHR MAC control element as defined in subclause 6.1.3.6 based on the value reported by the physical layer;
- start or restart *periodicPHR-Timer*;
- start or restart *prohibitPHR-Timer*;
- cancel all triggered PHR(s).

<...>

6.1.3.6 Power Headroom Report MAC Control Element

The Power Headroom Report (PHR) MAC control element is identified by a MAC PDU subheader with LCID as specified in table 6.2.1-2. It has a fixed size and consists of a single octet defined as follows (figure 6.1.3.6-1):

- R: reserved bit, set to "0";
- Power Headroom (PH): this field indicates the power headroom level. The length of the field is 6 bits. The reported PH and the corresponding power headroom levels are shown in Table 6.1.3.6-1 below (the corresponding measured values in dB can be found in subclause 9.1.8.4 of [9]).



6

• **Figure 6.1.3.6-1: PHR MAC control element**

7

Table 6.1.3.6-1: Power Headroom levels for PHR

PH	Power Headroom Level
0	POWER_HEADROOM_0
1	POWER_HEADROOM_1
2	POWER_HEADROOM_2
3	POWER_HEADROOM_3
...	...
60	POWER_HEADROOM_60
61	POWER_HEADROOM_61
62	POWER_HEADROOM_62
63	POWER_HEADROOM_63

6.1.3.6a Extended Power Headroom Report MAC Control Elements

For *extendedPHR*, the Extended Power Headroom Report (PHR) MAC control element is identified by a MAC PDU subheader with LCID as specified in table 6.2.1-2. It has a variable size and is defined in Figure 6.1.3.6a-2. When Type 2 PH is reported, the octet containing the Type 2 PH field is included first after the octet indicating the presence of PH per SCell and followed by an octet containing the associated $P_{\text{CMAX},c}$ field (if reported). Then follows in ascending order based on the *ServCellIndex* [8] an octet with the Type 1 PH field and an octet with the associated $P_{\text{CMAX},c}$ field (if reported), for the PCell and for each SCell indicated in the bitmap.

For *extendedPHR2*, the Extended Power Headroom Report (PHR) MAC control elements are identified by a MAC PDU subheader with LCID as specified in table 6.2.1-2. They have variable sizes and are defined in Figure 6.1.3.6a-3, Figure 6.1.3.6a-4 and Figure 6.1.3.6a-5. One octet with C fields is used for indicating the presence of PH per SCell when the highest *SCellIndex* of SCell with configured uplink is less than 8, otherwise four octets are used. When Type 2 PH is reported for the PCell, the octet containing the Type 2 PH field is included first after the octet(s) indicating the presence of PH per SCell and followed by an octet containing the associated $P_{\text{CMAX},c}$ field (if reported). Then follows the Type 2 PH field for the PUCCH SCell (if PUCCH on SCell is configured and Type 2 PH is reported for the PUCCH SCell), followed by an octet containing the associated $P_{\text{CMAX},c}$ field (if reported). Then follows in ascending order based on the *ServCellIndex* [8] an octet with the Type 1 PH field and an octet with the associated $P_{\text{CMAX},c}$ field (if reported), for the PCell and for each SCell indicated in the bitmap.

The Extended PHR MAC Control Elements are defined as follows:

- C_i : this field indicates the presence of a PH field for the SCell with *SCellIndex* i as specified in [8]. The C_i field set to "1" indicates that a PH field for the SCell with *SCellIndex* i is reported. The C_i field set to "0" indicates that a PH field for the SCell with *SCellIndex* i is not reported;
- R: reserved bit, set to "0";
- V: this field indicates if the PH value is based on a real transmission or a reference format. For Type 1 PH, V=0 indicates real transmission on PUSCH and V=1 indicates that a PUSCH reference format is used. For Type 2 PH, V=0 indicates real transmission on PUCCH and V=1 indicates that a PUCCH reference format is used. Furthermore, for both Type 1 and Type 2 PH, V=0 indicates the presence of the octet containing the associated $P_{\text{CMAX},c}$ field, and V=1 indicates that the octet containing the associated $P_{\text{CMAX},c}$ field is omitted;
- Power Headroom (PH): this field indicates the power headroom level. The length of the field is 6 bits. The reported PH and the corresponding power headroom levels are shown in Table 6.1.3.6-1 (the corresponding measured values in dB can be found in subclause 9.1.8.4 of [9]);
- P: this field indicates whether the MAC entity applies power backoff due to power management (as allowed by $P\text{-MPR}_c$ [10]). The MAC entity shall set P=1 if the corresponding $P_{\text{CMAX},c}$ field would have had a different value if no power backoff due to power management had been applied;

- $P_{\text{CMAX},c}$: if present, this field indicates the $P_{\text{CMAX},c}$ or $\tilde{P}_{\text{CMAX},c}$ [2] used for calculation of the preceding PH field. The reported $P_{\text{CMAX},c}$ and the corresponding nominal UE transmit power levels are shown in Table 6.1.3.6a-1 (the corresponding measured values in dBm can be found in subclause 9.6.1 of [9]).

8

- **Figure 6.1.3.6a-1: Void**

C ₇	C ₆	C ₅	C ₄	C ₃	C ₂	C ₁	R
P	V	PH (Type 2, PCell)					
R	R	P _{CMAX,c} 1					
P	V	PH (Type 1, PCell)					
R	R	P _{CMAX,c} 2					
P	V	PH (Type 1, SCell 1)					
R	R	P _{CMAX,c} 3					
...							
P	V	PH (Type 1, SCell n)					
R	R	P _{CMAX,c} m					

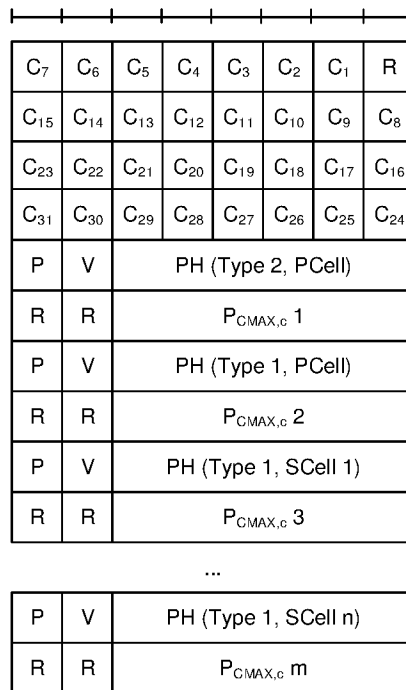
9

- **Figure 6.1.3.6a-2: Extended PHR MAC Control Element**

C ₇	C ₆	C ₅	C ₄	C ₃	C ₂	C ₁	R
P	V	PH (Type 2, PCell)					
R	R	P _{C_{MAX,c} 1}					
P	V	PH (Type 2, PUCCH SCell)					
R	R	P _{C_{MAX,c} 2}					
P	V	PH (Type 1, PCell)					
R	R	P _{C_{MAX,c} 3}					
P	V	PH (Type 1, SCell 1)					
R	R	P _{C_{MAX,c} 4}					
...							
P	V	PH (Type 1, SCell n)					
R	R	P _{C_{MAX,c} m}					

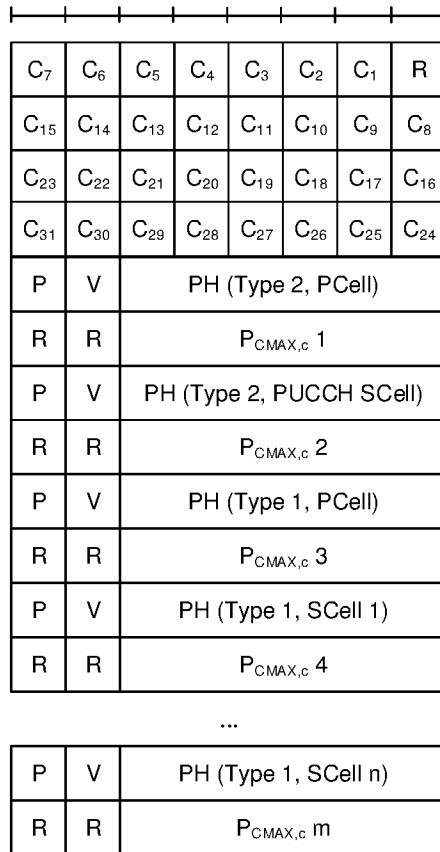
10

- **Figure 6.1.3.6a1-3: Extended PHR MAC Control Element supporting PUCCH on SCell**



11

- Figure 6.1.3.6a2-4: Extended PHR MAC Control Element supporting 32 serving cells with configured uplink



12

- **Figure 6.1.3.6a3-5: Extended PHR MAC Control Element supporting 32 serving cells with configured uplink and PUCCH on SCell**

13 Table 6.1.3.6a-1: Nominal UE transmit power level for Extended PHR and for Dual Connectivity PHR

P _{C_{MAX,c}}	Nominal UE transmit power level
0	PCMAX_C_00
1	PCMAX_C_01
2	PCMAX_C_02
...	...
61	PCMAX_C_61
62	PCMAX_C_62
63	PCMAX_C_63

Multiple pathloss references are introduced to facilitate power control for beam operation. Multiple reference signals can be configured for a UE as pathloss reference candidate. A base station could transmit different reference signals [on different beams or for different sounding reference signal resource index (SRI) or with different spatial precoder], such that pathloss for a beam or a SRI or a spatial precoder could be reflected by measuring a reference signal associated with the beam or SRI or spatial precoder. With properly compensation of different pathloss for different transmission [on different beam or with different SRI or with different spatial precoder], per beam/SRI/spatial precoder power control can be achieved with properly setting different transmission powers for

transmissions on different beams or different SRIs or different spatial precoder.

Note that in this application beam /SRI/precoder could mean the same thing and used interchangeably.

Which pathloss reference is used for deriving pathloss value for power control or power headroom derivation could be indicated by a base station for a transmission. For example, each value of SRI would be associated with a pathloss reference via RRC configuration and pathloss reference for a PUSCH could be selected or used for power control according to a SRI field in a DCI format scheduling the PUSCH transmission, e.g. a pathloss reference associated with the SRI is selected or used. When such SRI is not indicated, e.g. if the DCI does not comprise SRI or there is no DCI for a PUSCH, e.g. grant-free transmission or transmission with configured UL grant, or there is no PUSCH transmitted while virtual power headroom for a cell, some rule would be defined for determining a pathloss reference, by a UE or a base station. More details can be found in the following discussions:

In RAN1#89, RAN1 recognizes the necessity to take into account the pathloss differences among different beams in power control and made the following agreement:

Agreements:

- Support beam specific pathloss for ULPC

In RAN1#90bis meeting, details of implementing the above agreement were agreed in RAN1 by defining a power control formula with addition of pathloss reference indication:

Agreement

Support the following PUSCH power control in NR:

$$P_{\text{PUSCH},c}(i) = \min \left\{ P_{\text{CMAX},c}(i), \right. \\ \left. 10 \log_{10} (M_{\text{PUSCH},c}(i)) + P_{0,c}(j) + \alpha_c(j) \cdot PL_c(k) + \Delta_{TF,c}(i) + f_c(i, l) \right\}$$

- For the pathloss measurement RS indication.
- k is indicated by beam indication for PUSCH (if present)
- A linkage between PUSCH beam indication and k which is index of downlink RS resource for PL measurement is pre-configured via high layer signal
- Only one value k is RRC configured in UE specific way if PUSCH beam indication is not present

In RAN1#91, RAN1 further clarifies beam indication for PUSCH is equivalent to SRI field in UL grant and it was agreed to configure up to 4 pathloss reference:

Agreement:

- For PUSCH PC, when SRI field is configured, confirm the agreed expression of “PUSCH beam indication (if present)” is the same as “indication by SRI field in UL grant (if present)”, aligning to MIMO agreements at least for grant-based PUSCH.
- FFS: The case where SRI field is not configured

Agreement:

- The maximum total number of PL estimates for PUSCH, PUCCH, and SRS that can be configured to a UE is limited to 4 per cell

In RAN1#1801Adhoc, RAN1 agreed mapping between value in SRI field and pathloss reference are configured by RRC for grant based PUSCH. For configured grant type 1 PUSCH, pathloss reference is directly configured by RRC. For configured grant type 2 PUSCH, :

Agreement:

Define RRC parameter SRI-PUSCHPowerControl-Mapping which contains the following, where N_s is the number of valid values for the SRI field in the DCI (as defined in 38.212)

- SRI-PathlossReferenceIndex-Mapping contains N_s pathloss reference ID values (Note: Maximum of four pathloss reference IDs can be configured) with the first value corresponding to SRI state 0, second value corresponding to SRI state 1 etc.

Agreement:

Add RRC parameter PathlossReferenceIndex at least for *UL-TWG-type1*

In RAN1#92, RAN1 agreed pathloss reference would be indicated by activation DCI for configured grant type 2 PUSCH:

Agreement:

For the indication of $\{k\}$ for PUSCH UL-TWG-type2:

- Do NOT introduce one new RRC parameter *PathlossReferenceIndex* into *UL-TWG-type2* and the pathloss reference index will be based on activation DCI for UL-TWG-type2

In RAN1#92 bis, RAN1 agreed there would be default pathloss reference for the case of virtual PHR and Msg3:

Agreement

Default parameter setting for virtual PHR

How to set $\{j, q_d, l\}$

- For j , $P0alphasetindex = 0$ of *p0-pusch-alpha-setconfig*
- For q_d , *pusch-pathlossreference-index* = 0 of *pusch-pathloss-Reference-rs*
- For l , $l = 0$
- Note: If the UE is configured with multiple UL BWPs, j , q_d , l corresponding to lowest BWP ID are used

Agreement

For PUSCH Msg3 in the RRC_CONNECTED state, UE shall use the SSB or CSI-RS associated with the PRACH for the pathloss measurement

More detail could be found in the following quotation from[10]:

7 Uplink Power control

Uplink power control determines the transmit power of the different uplink physical channels or signals.

7.1 Physical uplink shared channel

For PUSCH, a UE first scales a linear value $\hat{P}_{\text{PUSCH},b,f,c}(i,j,q_d,l)$ of the transmit power $P_{\text{PUSCH},b,f,c}(i,j,q_d,l)$ on UL BWP b , as described in Subclause 12, of carrier f of serving cell c , with parameters as defined in Subclause 7.1.1, by the ratio of the number of antenna ports with a non-zero PUSCH transmission to the number of configured antenna ports for the transmission scheme. The resulting scaled power is then split equally across the antenna ports on which the non-zero PUSCH is transmitted. The UL BWP b is the active UL BWP.

7.1.1 UE behaviour

If a UE transmits a PUSCH on UL BWP b of carrier f of serving cell c using parameter set configuration with index j and PUSCH power control adjustment state with index l , the UE determines the PUSCH transmission power $P_{\text{PUSCH},b,f,c}(i,j,q_d,l)$ in PUSCH transmission period i as

$$P_{\text{PUSCH},b,f,c}(i,j,q_d,l) = \min \left\{ \begin{array}{l} P_{\text{CMAX},f,c}(i), \\ P_{\text{O_PUSCH},b,f,c}(j) + 10 \log_{10} (2^{\mu} \cdot M_{\text{RB},b,f,c}^{\text{PUSCH}}(i)) + \alpha_{b,f,c}(j) \cdot PL_{b,f,c}(q_d) + \Delta_{\text{TF},b,f,c}(i) + f_{b,f,c}(i,l) \end{array} \right\} \text{ [dBm]}$$

where,

- $P_{\text{CMAX},f,c}(i)$ is the configured UE transmit power defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2] for carrier f of serving cell c in PUSCH transmission period i .
- $P_{\text{O_PUSCH},b,f,c}(j)$ is a parameter composed of the sum of a component $P_{\text{O_NOMINAL_PUSCH},b,f,c}(j)$ and a component $P_{\text{O_UE_PUSCH},b,f,c}(j)$ where $j \in \{0, 1, \dots, J-1\}$.
 - If a UE is not provided with higher layer parameter *P0-PUSCH-AlphaSet* or for a Msg3 PUSCH transmission as described in Subclause 8.3, $j = 0$, $P_{\text{O_UE_PUSCH},b,f,c}(0) = 0$, and $P_{\text{O_NOMINAL_PUSCH},b,f,c}(0) = P_{\text{O_PRE}} + \Delta_{\text{PREAMBLE_Msg3}}$, where the parameter *preambleReceivedTargetPower* [11, TS 38.321] (for $P_{\text{O_PRE}}$) and *msg3-DeltaPreamble* (for $\Delta_{\text{PREAMBLE_Msg3}}$) are provided by higher layers for carrier f of serving cell c .
 - For a PUSCH (re)transmission configured by higher layer parameter *ConfiguredGrantConfig*, $j = 1$, $P_{\text{O_NOMINAL_PUSCH},b,f,c}(1)$ is provided by higher layer parameter *p0-NominalWithoutGrant*, and $P_{\text{O_UE_PUSCH},b,f,c}(1)$ is provided by higher layer parameter *p0* obtained from *p0-PUSCH-Alpha* in *ConfiguredGrantConfig* that provides an index *P0-PUSCH-AlphaSetId* to a set of higher layer parameters *P0-PUSCH-AlphaSet* for UL BWP b of carrier f of serving cell c .
 - For $j \in \{2, \dots, J-1\} = S_j$, a $P_{\text{O_NOMINAL_PUSCH},b,f,c}(j)$ value, applicable for all $j \in S_j$, is provided by higher layer parameter *p0-NominalWithGrant* for each carrier f of serving cell c and a set of $P_{\text{O_UE_PUSCH},b,f,c}(j)$ values are provided by a set of higher layer parameters *p0* in *P0-PUSCH-AlphaSet* indicated by a respective set of higher layer parameters *p0-PUSCH-AlphaSetId* for UL BWP b of carrier f of serving cell c .
 - If the UE is provided by higher layer parameter *SRI-PUSCH-PowerControl* more than one values of *p0-PUSCH-AlphaSetId* and if DCI format 0_1 includes a SRI field, the UE obtains a mapping from higher layer parameter *sri-PUSCH-PowerControlId* in *SRI-PUSCH-PowerControl* between a set of values for the SRI field in DCI format 0_1 [5, TS 38.212] and a set of indexes provided by higher layer parameter *p0-PUSCH-AlphaSetId* that map to a set of *P0-PUSCH-AlphaSet* values. If

the PUSCH transmission is scheduled by a DCI format 0_1, the UE determines the values of $P_{O_UE_PUSCH,b,f,c}(j)$ from the $p0alphasetindex$ value that is mapped to the SRI field value. - If the PUSCH transmission is scheduled by a DCI format 0_0 or by a DCI format 0_1 that does not include a SRI field, or if a higher layer parameter *SRI-P0AlphaSetIndex-Mapping* is not provided to the UE, the UE determines $P_{O_UE_PUSCH,b,f,c}(j)$ from the first *p0-pusch-alpha-set* in *p0-pusch-alpha-setconfig* for all $j \in S_j$.

- For $\alpha_{b,f,c}(j)$
 - For $j = 0$, $\alpha_{b,f,c}(0)$ is a value of higher layer parameter *msg3-Alpha*, when provided; otherwise, $\alpha_{b,f,c}(0) = 1$.
 - For $j = 1$, $\alpha_{b,f,c}(1)$ is provided by higher layer parameter *alpha* obtained from *p0-PUSCH-Alpha* in *ConfiguredGrantConfig* providing an index *P0-PUSCH-AlphaSetId* to a set of higher layer parameters *P0-PUSCH-AlphaSet* for UL BWP b of carrier f of serving cell c .
 - For $j \in S_j$, a set of $\alpha_{b,f,c}(j)$ values are provided by a set of higher layer parameters *p0-NominalWithGrant* for each carrier f of serving cell c and a set of the UE does not accumulate corresponding values are provided by a set of higher layer parameters *alpha* in *P0-PUSCH-AlphaSet* indicated by a respective set of higher layer parameters *p0-PUSCH-AlphaSetId* for UL BWP b of carrier f of serving cell c .
 - If the UE is provided a higher layer parameter *SRI-PUSCH-PowerControl* and more than one values of *p0-PUSCH-AlphaSetId*, DCI format 0_1 includes a SRI field and the UE obtains a mapping from higher layer parameter *sri-PUSCH-PowerControlId* in *SRI-PUSCH-PowerControl* between a set of values for the SRI field in DCI format 0_1 [5, TS 38.212] and a set of indexes provided by higher layer parameter *p0-PUSCH-AlphaSetId* that map to a set of *P0-PUSCH-AlphaSet* values. If the PUSCH transmission is scheduled by a DCI format 0_1, the UE determines the values of $\alpha_{b,f,c}(j)$ from the $p0alphasetindex$ value that is mapped to the SRI field value. - If the PUSCH transmission is scheduled by a DCI format 0_0 or by a DCI format 0_1 that does not include a SRI field, or if a higher layer parameter *SRI-P0AlphaSetIndex-Mapping* is not provided to the UE, the UE determines $\alpha_{b,f,c}(j)$ from the first *p0-pusch-alpha-set* in *p0-pusch-alpha-setconfig* for all $j \in S_j$.
- $M_{RB,b,f,c}^{PUSCH}(i)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks for PUSCH transmission period i on UL BWP b of carrier f of serving cell c and μ is defined in [4, TS 38.211].
- $PL_{b,f,c}(q_d)$ is a downlink path-loss estimate in dB calculated by the UE using reference signal (RS) index q_d for a DL BWP that is paired with UL BWP b of carrier f of serving cell c .
 - If the UE is not provided with higher layer parameter *PUSCH-PathlossReferenceRS* and before the UE is provided with dedicated higher layer parameters, the UE identifies a RS index from the SS/PBCH block index that the UE obtains higher layer parameter *MasterInformationBlock*.
 - If the UE is configured with a number of RS resource indexes up to the value of higher layer parameter *maxNrofPUSCH-PathlossReferenceRSs* and a respective set of RS configurations for the number of RS resource indexes by higher layer parameter *PUSCH-PathlossReferenceRS*. The set of RS resource indexes can include one or both of a set of SS/PBCH block indexes, each provided by higher layer parameter *ssb-Index* when a value of a corresponding higher layer parameter *pusch-PathlossReferenceRS-Id* maps to a SS/PBCH block index, and a set of CSI-RS resource indexes, each provided by higher layer parameter *csi-RS-Index* when a value of a

corresponding higher layer parameter *pusch-PathlossReferenceRS-Id* maps to a CSI-RS resource index. The UE identifies a RS resource index in the set of RS resource indexes to correspond either to a SS/PBCH block index or to a CSI-RS resource index as provided by higher layer parameter *pusch-PathlossReferenceRS-Id* in *PUSCH-PathlossReferenceRS*.

- If the PUSCH is an Msg3 PUSCH, the UE uses the same RS resource index as for a corresponding PRACH transmission.
- If the UE is provided a higher layer parameter *SRI-PUSCH-PowerControl* and more than one values of *PUSCH-PathlossReferenceRS-Id*, the UE obtains a mapping from higher layer parameter *sri-PUSCH-PowerControlId* in *SRI-PUSCH-PowerControl* between a set of values for the SRI field in DCI format 0_1 and a set of *PUSCH-PathlossReferenceRS-Id* values. If the PUSCH transmission is scheduled by a DCI format 0_1, DCI format 0_1 includes a SRI field and the UE determines the RS resource q_d from the value of *pusch-pathlossreference-index* that is mapped to the SRI field value.
- If the PUSCH transmission is scheduled by a DCI format 0_0 or by a DCI format 0_1 that does not include a SRI field, or if a higher layer parameter *SRI-PathlossReferenceIndex-Mapping* is not provided to the UE, the UE determines a RS resource with a respective higher layer parameter *pusch-pathlossreference-index* value being equal to zero.
- For a PUSCH transmission configured by higher layer parameter *ConfiguredGrantConfig*, if higher layer parameter *rrc-ConfiguredUplinkGrant* in *ConfiguredGrantConfig* includes higher layer parameter *pathlossReferenceIndex*, a RS resource index q_d is provided by a value of higher layer parameter *pathlossReferenceIndex*.
- For a PUSCH transmission configured by higher layer parameter *ConfiguredGrantConfig*, if higher layer parameter *rrc-ConfiguredUplinkGrant* in *ConfiguredGrantConfig* does not include higher layer parameter *pathlossReferenceIndex*, the UE determines the RS resource q_d from the value of *PUSCH-PathlossReferenceRS-Id* that is mapped to the SRI field value in the DCI format activating the PUSCH transmission. If the DCI format activating the PUSCH transmission does not include a SRI field, the UE determines a RS resource with a respective higher layer parameter *PUSCH-PathlossReferenceRS-Id* value being equal to zero.

$PL_{b,f,c}(q_d) = referenceSignalPower -$ higher layer filtered RSRP, where *referenceSignalPower* is provided by higher layers and RSRP is defined in [7, TS 38.215] for the reference serving cell and the higher layer filter configuration is defined in [12, TS 38.331] for the reference serving cell.

For $j = 0$, *referenceSignalPower* is provided by higher layer parameter *ss-PBCH-BlockPower*. For $j > 0$, *referenceSignalPower* is configured by either higher layer parameter *ss-PBCH-BlockPower* or, when periodic CSI-RS transmission is configured, by higher layer parameter *powerControlOffsetSS* providing an offset of the CSI-RS transmission power relative to the SS/PBCH block transmission power [6, TS 38.214].

- $\Delta_{TF,b,f,c}(i) = 10 \log_{10} \left(\left(2^{BP_{RE} K_s} - 1 \right) \cdot \beta_{offset}^{PUSCH} \right)$ for $K_s = 1.25$ and $\Delta_{TF,b,f,c}(i) = 0$ for $K_s = 0$ where K_s is provided by higher layer parameter *deltaMCS* provided for each UL BWP b of each carrier f and serving cell c . If the PUSCH transmission is over more than one layer [6, TS 38.214], $\Delta_{TF,b,f,c}(i) = 0$. BP_{RE} and β_{offset}^{PUSCH} , for each UL BWP b of each carrier f and each serving cell c , are computed as below.

- $BP_{RE} = \sum_{r=0}^{C-1} K_r / N_{RE}$ for PUSCH with UL-SCH data and $BP_{RE} = O_{CSI} / N_{RE}$ for CSI transmission in a PUSCH without UL-SCH data, where

- C is the number of code blocks, K_r is the size for code block r , O_{CSI} is the number of CSI part 1 bits including CRC bits, and N_{RE} is the number of resource elements determined as
$$N_{\text{RE}} = M_{\text{RB},b,f,c}^{\text{PUSCH}}(i) \cdot \sum_{j=0}^{N_{\text{sym},b,f,c}^{\text{PUSCH}}(i)-1} N_{\text{sc,data}}^{\text{RB}}(i,j),$$
where $N_{\text{sym},b,f,c}^{\text{PUSCH}}(i)$ is the number of symbols for PUSCH transmission period i on UL BWP b of carrier f of serving cell c , $N_{\text{sc,data}}^{\text{RB}}(i,j)$ is a number of subcarriers excluding DM-RS subcarriers in PUSCH symbol j , $0 \leq j < N_{\text{sym},b,f,c}^{\text{PUSCH}}(i)$, and C , K_r are defined in [5, TS 38.212].
- $\beta_{\text{offset}}^{\text{PUSCH}} = 1$ when the PUSCH includes UL-SCH data and $\beta_{\text{offset}}^{\text{PUSCH}} = \beta_{\text{offset}}^{\text{CSI,1}}$, as described in Subclause 9.3, when the PUSCH includes CSI and does not include UL-SCH data.
- For the PUSCH power control adjustment state for UL BWP b of carrier f of serving cell c in PUSCH transmission period i
 - $\delta_{\text{PUSCH},b,f,c}(i - K_{\text{PUSCH}}, l)$ is a correction value, also referred to as a TPC command, and is included in a DCI format 0_0 or DCI format 0_1 that schedules the PUSCH transmission period i on UL BWP b of carrier f of serving cell c or jointly coded with other TPC commands in a DCI format 2_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, as described in Subclause 11.3, that is last received by the UE prior to the PUSCH transmission;
 - $l \in \{0, 1\}$ if the UE is configured with higher layer parameter *twoPUSCH-PC-AdjustmentStates*, and $l = 0$ if the UE is not configured with higher layer parameter *twoPUSCH-PC-AdjustmentStates* or if the PUSCH is a Msg3 PUSCH.
 - For a PUSCH (re)transmission configured by higher layer parameter *ConfiguredGrantConfig*, the value of $l \in \{0, 1\}$ is provided to the UE by higher layer parameter *powerControlLoopToUse*
 - If the UE is provided a higher layer parameter *SRI-PUSCH-PowerControl*, the UE obtains a mapping between a set of values for the SRI field in DCI format 0_1 and the l value(s) provided by higher layer parameter *sri-PUSCH-ClosedLoopIndex*. If the PUSCH transmission is scheduled by a DCI format 0_1 and if DCI format 0_1 includes a SRI field, the UE determines the l value that is mapped to the SRI field value
 - If the PUSCH transmission is scheduled by a DCI format 0_0 or by a DCI format 0_1 that does not include a SRI field, or if a higher layer parameter *SRI-PUSCH-PowerControl* is not provided to the UE, $l = 0$
- $f_{b,f,c}(i, l) = f_{b,f,c}(i - 1, l) + \delta_{\text{PUSCH},b,f,c}(i - K_{\text{PUSCH}}, l)$ is the PUSCH power control adjustment state for UL BWP b of carrier f of serving cell c and PUSCH transmission period i if accumulation is enabled based on higher layer parameter *tpc-Accumulation*, where
 - $\delta_{\text{PUSCH},b,f,c}(i - K_{\text{PUSCH}}, l) = 0$ dB if the UE does not detect a TPC command for UL BWP b of carrier f of serving cell c .
 - If the PUSCH transmission is in response to a PDCCH decoding with DCI format 0_0 or DCI format 0_1, or 2_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, the respective $\delta_{\text{PUSCH},b,f,c}$ accumulated values are given in Table 7.1.1-1.
 - If the UE has reached $P_{\text{CMAX},f,c}(i)$ for UL BWP b of carrier f of serving cell c , the UE does not accumulate positive TPC commands for UL BWP b of carrier f of serving cell c .

- If UE has reached minimum power for UL BWP b of carrier f of serving cell c , the UE does not accumulate negative TPC commands for UL BWP b of carrier f of serving cell c .
- A UE resets accumulation for UL BWP b of carrier f of serving cell c
 - When $P_{O_UE_PUSCH,b,f,c}(j)$ value is changed by higher layers;
 - When $P_{O_UE_PUSCH,b,f,c}(j)$ value is received by higher layers and serving cell c is a secondary cell;
 - When $\alpha_{f,b,c}(j)$ value is changed by higher layers;
- If $j > 1$, the PUSCH transmission is scheduled by a DCI format 0_1 that includes a SRI field, and the UE is provided higher layer parameter *SRI-PUSCH-PowerControl*, the UE determines the value of l from the value of j based on an indication by the SRI field for a *sri-PUSCH-PowerControlId* value associated with the *sri-P0-PUSCH-AlphaSetId* value corresponding to j and with the *sri-PUSCH-ClosedLoopIndex* value corresponding to l
- If $j > 1$ and the PUSCH transmission is scheduled by a DCI format 0_0 or by a DCI format 0_1 that does not include a SRI field or the UE is not provided higher layer parameter *SRI-PUSCH-PowerControl*, $l = 0$
- If $j = 1$, l is provided by the value of higher layer parameter *powerControlLoopToUse*
- $f_{b,f,c}(0,l) = 0$ is the first value after reset of accumulation.
- $f_{b,f,c}(i,l) = \delta_{PUSCH,b,f,c}(i - K_{PUSCH}, l)$ is the PUSCH power control adjustment state for UL BWP b of carrier f of serving cell c and PUSCH transmission period i if accumulation is not enabled based on higher layer parameter *tpc-Accumulation*, where
 - If the PUSCH transmission is in response to a PDCCH decoding with DCI format 0_0 or DCI format 0_1, or 2_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI, the respective $\delta_{PUSCH,b,f,c}$ absolute values are given in Table 7.1.1-1.
 - $f_{b,f,c}(i,l) = f_{b,f,c}(i-1,l)$ for a PUSCH transmission period where the UE does not detect a DCI format 0_0 or DCI format 0_1, or 2_2 having CRC parity bits scrambled by TPC-PUSCH-RNTI UL BWP b of for carrier f of serving cell c .
- If the UE receives the random access response message for UL BWP b of carrier f of serving cell c
 - $f_{b,f,c}(0,l) = \Delta P_{rampup,b,f,c} + \delta_{msg2,b,f,c}$, where $l = 0$ and
 - $\delta_{msg2,b,f,c}$ is the TPC command indicated in the random access response grant of the random access response message corresponding to the random access preamble transmitted on UL BWP b of carrier f in the serving cell c , and

$$\Delta P_{rampup,b,f,c} = \min \left[\left\{ \max \left(0, P_{C_{MAX},f,c} - \left(10 \log_{10} (2^{\mu} \cdot M_{RB,b,f,c}^{PUSCH}(0)) + P_{O_PUSCH,b,f,c}(0) + \alpha_{b,f,c}(0) \cdot PL_c + \Delta_{TF,b,f,c}(0) + \delta_{msg2,b,f,c} \right) \right) \right\}, \Delta P_{rampuprequested,b,f,c} \right]$$

and $\Delta P_{\text{rampuprequested},b,f,c}$ is provided by higher layers and corresponds to the total power ramp-up requested by higher layers from the first to the last random access preamble for carrier f in the serving cell c , $M_{\text{RB},b,f,c}^{\text{PUSCH}}(0)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks for the first PUSCH transmission on UL BWP b of carrier f of serving cell c , and $\Delta_{\text{TF},b,f,c}(0)$ is the power adjustment of first PUSCH transmission on UL BWP b of carrier f of serving cell c .

Table 7.1.1-1: Mapping of TPC Command Field in DCI format 0_0, DCI format 0_1, or DCI format 2_2, having CRC parity bits scrambled by TPC-PUSCH-RNTI, or DCI format 2_3, to absolute and accumulated $\delta_{\text{PUSCH},b,f,c}$ values or $\delta_{\text{SRS},b,f,c}$ values

• TPC Command Field	• Accumulated $\delta_{\text{PUSCH},b,f,c}$ or $\delta_{\text{SRS},b,f,c}$ [dB]	• Absolute $\delta_{\text{PUSCH},b,f,c}$ or $\delta_{\text{SRS},b,f,c}$ [dB]
★ 0	★ -1	★ -4
★ 1	★ 0	★ -1
★ 2	★ 1	★ 1
★ 3	★ 3	★ 4

7.2 Physical uplink control channel

If the UE is configured with a SCG, the UE shall apply the procedures described in this subclause for both MCG and SCG.

- When the procedures are applied for MCG, the term 'serving cell' in this subclause refers to serving cell belonging to the MCG.

When the procedures are applied for SCG, the term 'serving cell' in this subclause refers to serving cell belonging to the SCG. The term 'primary cell' in this subclause refers to the PSCell of the SCG. If the UE is configured with a PUCCH-SCell, the UE shall apply the procedures described in this subclause for both primary PUCCH group and secondary PUCCH group.

- When the procedures are applied for the primary PUCCH group, the term 'serving cell' in this subclause refers to serving cell belonging to the primary PUCCH group.
- When the procedures are applied for the secondary PUCCH group, the term 'serving cell' in this subclause refers to serving cell belonging to the secondary PUCCH group. The term 'primary cell' in this subclause refers to the PUCCH-SCell of the secondary PUCCH group.

7.2.1 UE behaviour

If a UE transmits a PUCCH on active UL BWP b of carrier f in the primary cell c using PUCCH power control adjustment state with index l , the UE determines the PUCCH transmission power

$P_{\text{PUCCH},b,f,c}(i, q_u, q_d, l)$ in PUCCH transmission period i as

$$P_{\text{PUCCH},b,f,c}(i, q_u, q_d, l) = \min \left\{ P_{\text{CMAX},f,c}(i), \left[P_{\text{O-PUCCH},b,f,c}(q_u) + 10 \log_{10} (2^{\mu} \cdot M_{\text{RB},b,f,c}^{\text{PUSCH}}(i)) + PL_{b,f,c}(q_d) + \Delta_{\text{F-PUCCH}}(F) + \Delta_{\text{TF},b,f,c}(i) + g_{b,f,c}(i, l) \right] \right\} \text{ [dBm]}$$

where

- $P_{\text{CMAX},f,c}(i)$ is the configured UE transmit power defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2] for carrier f of serving cell c in PUCCH transmission period i .
- $P_{\text{O_PUCCH},b,f,c}(q_u)$ is a parameter composed of the sum of a component $P_{\text{O_NOMINAL_PUCCH}}$, provided by higher layer parameter *p0-nominal* for carrier f of primary cell c , and a component $P_{\text{O_UE_PUCCH}}(q_u)$ provided by higher layer parameter *p0-PUCCH-Value* in *P0-PUCCH* for UL BWP b of carrier f of primary cell c , where $0 \leq q_u < Q_u$. Q_u is a size for a set of $P_{\text{O_UE_PUCCH}}$ values provided by higher layer parameter *maxNrofPUCCH-P0-PerSet*. The set of $P_{\text{O_UE_PUCCH}}$ values is provided by higher layer parameter *p0-Set*.
 - If the UE is provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by an index provided by higher layer parameter *p0-PUCCH-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of *p0-PUCCH-Value* values. If the UE is provided more than one values for *pucch-SpatialRelationInfoId* and the UE receives an activation command [11, TS 38.321] indicating a value of *pucch-SpatialRelationInfoId*, the UE determines the *p0-PUCCH-Value* value through the link to a corresponding *p0-PUCCH-Id* index. The UE applies the activation command 3 msec after a slot where the UE transmits HARQ-ACK information for the PDSCH providing the activation command.
 - If the UE is not provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains the *p0-PUCCH-Value* value from the *P0-PUCCH* with *p0-PUCCH-Id* index 0 in *p0-Set*.
- $M_{\text{RB},b,f,c}^{\text{PUCCH}}(i)$ is the bandwidth of the PUCCH resource assignment expressed in number of resource blocks for PUCCH transmission period i on UL BWP b of carrier f of serving cell c and μ is defined in [4, TS 38.211].
- $PL_{b,f,c}(q_d)$ is a downlink path-loss estimate in dB calculated by the UE using reference signal (RS) index q_d for a DL BWP that is paired with UL BWP b of carrier f of serving cell c .
- $PL_{b,f,c}(q_d)$ is a downlink path-loss estimate in dB calculated by the UE using reference signal (RS) index q_d for a DL BWP that is paired with UL BWP b of carrier f of the primary cell c .
 - If the UE is not provided higher layer parameter *pathlossReferenceRSs* and before the UE is provided with dedicated higher layer parameters, the UE calculates $PL_{b,f,c}(q_d)$ using a RS resource obtained from the SS/PBCH block that the UE obtains higher layer parameter *MasterInformationBlock*.
 - If the UE is provided a number of RS resource indexes, the UE calculates $PL_{b,f,c}(q_d)$ using RS resource q_d , where $0 \leq q_d < Q_d$. Q_d is a size for a set of RS resources provided by higher layer parameter *maxNrofPUCCH-PathlossReferenceRSs*. The set of RS resources is provided by higher layer parameter *pathlossReferenceRSs*. The set of RS resources can include one or both of a set of SS/PBCH block indexes, each provided by higher layer parameter *ssb-Index* in *PUCCH-PathlossReferenceRS* when a value of a corresponding higher layer parameter *pucch-PathlossReferenceRS-Id* maps to a SS/PBCH block index, and a set of CSI-RS resource indexes, each provided by higher layer parameter *csi-RS-Index* when a value of a corresponding higher layer parameter *pucch-PathlossReferenceRS-Id* maps to a CSI-RS resource index. The UE identifies a RS resource in the set of RS resources to correspond either to a SS/PBCH block index or to a CSI-RS resource index as provided by higher layer parameter *pucch-PathlossReferenceRS-Id* in *PUCCH-PathlossReferenceRS*.
 - If the UE is provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by indexes provided by corresponding higher layer parameters *pucch-PathlossReferenceRS-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of *referencesignal* values provided by

higher layer parameter *PUCCH-PathlossReferenceRS*. If the UE is provided more than one values for *pucch-SpatialRelationInfo* and the UE receives an activation command [11, TS 38.321] indicating a value of *pucch-SpatialRelationInfo*, the UE determines the *referencesignal* value in *PUCCH-PathlossReferenceRS* through the link to a corresponding *pucch-PathlossReferenceRS-Id* index. The UE applies the activation command 3 msec after a slot where the UE transmits HARQ-ACK information for the PDSCH providing the activation command.

- If the UE is not provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains the *referencesignal* value in *PUCCH-PathlossReferenceRS* from the *pucch-PathlossReferenceRS-Id* with index 0 in *PUCCH-PathlossReferenceRSs*.
- The parameter $\Delta_{F_PUCCH}(F)$ is provided by higher layer parameter *deltaF-PUCCH-f0* for PUCCH format 0, *deltaF-PUCCH-f1* for PUCCH format 1, *deltaF-PUCCH-f2* for PUCCH format 2, *deltaF-PUCCH-f3* for PUCCH format 3, and *deltaF-PUCCH-f4* for PUCCH format 4.
- $\Delta_{TF,b,f,c}(i)$ is a PUCCH transmission power adjustment component for UL BWP *b* of carrier *f* of primary cell *c*.

- For a PUCCH transmission using PUCCH format 0 or PUCCH format 1,

$$\Delta_{TF,b,f,c}(i) = 10 \log_{10} \left(\frac{N_{ref}^{PUCCH}}{N_{symb}^{PUCCH}} \right) \text{ where}$$

- N_{symb}^{PUCCH} is the number of PUCCH format 0 symbols or PUCCH format 1 symbols, provided by higher layer parameter *nrofSymbols* in *PUCCH-format0* or in *PUCCH-format1*, respectively
- $N_{ref}^{PUCCH} = 2$ for PUCCH format 0
- $N_{ref}^{PUCCH} = N_{symb}^{slot}$ for PUCCH format 1
- For a PUCCH transmission using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 and for a number of UCI bits smaller than or equal to 11,

$$\Delta_{TF,b,f,c}(i) = 10 \log_{10} (K_1 \cdot (n_{HARQ-ACK} + O_{SR} + O_{CSI}) / N_{RE})$$
 - $n_{HARQ-ACK}$ is a number of HARQ-ACK information bits that the UE determines as described in Subclause 9.1.2.1 for Type-1 HARQ-ACK codebook and as described in Subclause 9.1.3.1 for Type-2 HARQ-ACK codebook. If the UE is not provided with higher layer parameter *pdsch-HARQ-ACK-Codebook*, $n_{HARQ-ACK} = 1$ if the UE includes a HARQ-ACK information bit in the PUCCH transmission; otherwise, $n_{HARQ-ACK} = 0$.
 - O_{SR} is a number of SR information bits that the UE determines as described in Subclause 9.2.5.1.
 - O_{CSI} is a number of CSI information bits that the UE determines as described in Subclause 9.2.5.2.
 - N_{RE} is a number of resource elements determined as $N_{RE} = M_{RB,b,f,c}^{PUCCH}(i) \cdot N_{sc,ctrl}^{RB} \cdot N_{symb,b,f,c}^{PUCCH}(i)$, where $N_{sc,ctrl}^{RB}$ is a number of subcarriers per resource block excluding subcarriers used for DM-RS transmission, and $N_{symb-UCI,b,f,c}^{PUCCH}(i)$ is a number of symbols excluding symbols used for DM-RS transmission, as defined in Subclause 9.2.5.2, for PUCCH transmission period *i* on UL BWP *b* of carrier *f* of serving cell *c*.

- For a PUCCH transmission using PUCCH format 2 or PUCCH format 3 or PUCCH format 4 and for a number of UCI bits larger than 11, $\Delta_{\text{TF},b,f,c}(i) = 10 \log_{10} \left(\left(2^{K_2 \cdot \text{BPRE}} - 1 \right) \right)$.
- $\text{BPRE} = (O_{\text{ACK}} + O_{\text{SR}} + O_{\text{CSI}} + O_{\text{CRC}}) / N_{\text{RE}}$.
- O_{ACK} is a number of HARQ-ACK information bits that the UE determines as described in Subclause 9.1.2.1 for Type-1 HARQ-ACK codebook and as described in Subclause 9.1.3.1 for Type-2 HARQ-ACK codebook. If the UE is not provided with higher layer parameter *pdsch-HARQ-ACK-Codebook*, $O_{\text{ACK}} = 1$ if the UE includes a HARQ-ACK information bit in the PUCCH transmission; otherwise, $O_{\text{ACK}} = 0$.
- O_{SR} is a number of SR information bits that the UE determines as described in Subclause 9.2.5.1.
- O_{CSI} is a number of CSI information bits that the UE determines as described in Subclause 9.2.5.2.
- N_{RE} is a number of resource elements that the UE determines as $N_{\text{RE}} = M_{\text{RB},b,f,c}^{\text{PUCCH}}(i) \cdot N_{\text{sc,ctrl}}^{\text{RB}} \cdot N_{\text{symb-UCL},b,f,c}^{\text{PUCCH}}(i)$, where $N_{\text{sc,ctrl}}^{\text{RB}}$ is a number of subcarriers per resource block excluding subcarriers used for DM-RS transmission, and $N_{\text{symb-UCL},b,f,c}^{\text{PUCCH}}(i)$ is a number of symbols excluding symbols used for DM-RS transmission, as defined in Subclause 9.2.5.2, for PUCCH transmission period i on UL BWP b of carrier f of serving cell c .
- For the PUCCH power control adjustment state for UL BWP b of carrier f of primary cell c and PUCCH transmission period i
 - $\delta_{\text{PUCCH},b,f,c}(i - K_{\text{PUCCH}}, l)$ is a correction value, also referred to as a TPC command, and is included in a DCI format 1_0 or DCI format 1_1 for UL BWP b of carrier f of the primary cell c that the UE detects in PUCCH transmission period $i - K_{\text{PUCCH}}$, or jointly coded with other TPC commands in a DCI format 2_2 having CRC parity bits scrambled by TPC-PUCCH-RNTI [5, TS 36.212], as described in Subclause 11.3, where $l \in \{0, 1\}$ if the UE is provided higher layer parameter *twoPUCCH-PC-AdjustmentStates* and $l = 0$ if the UE is not provided higher layer parameter *twoPUCCH-PC-AdjustmentStates* or *PUCCH-SpatialRelationInfo*
 - If the UE is provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE obtains a mapping, by an index provided by higher layer parameter *p0-PUCCH-Id*, between a set of *pucch-SpatialRelationInfoId* values and a set of values for higher layer parameter *closedLoopIndex* that provide the l value(s). If the UE receives an activation command indicating a value of *pucch-SpatialRelationInfoId*, the UE determines the value *closedLoopIndex* that provides the value of l through the link to a corresponding *p0-PUCCH-Id* index.
 - The $\delta_{\text{PUCCH},b,f,c}$ dB values signalled on PDCCH with DCI format 1_0 or DCI format 1_1 or DCI format 2_2 having CRC parity bits scrambled by TPC-PUCCH-RNTI are given in Table 7.2.1-1.
 - $\delta_{\text{PUCCH},b,f,c}(i - K_{\text{PUCCH}}, l) = 0$ dB if the UE does not detect a TPC command for UL BWP b of carrier f of the primary cell c .
 - $g_{b,f,c}(i, l) = g_{b,f,c}(i - 1, l) + \delta_{\text{PUCCH},b,f,c}(i - K_{\text{PUCCH}}, l)$ is the current PUCCH power control adjustment state and $g_{b,f,c}(0, l) = 0$ is the first value after reset
 - If $P_{\text{O_PUCCH},b,f,c}(q_u)$ value is changed by higher layers,

$$- \quad g_{b,f,c}(0,l) = 0$$

If the UE is provided higher layer parameter *PUCCH-SpatialRelationInfo*, the UE determines the value of l from the value of q_u based on a *pucch-SpatialRelationInfoId* value associated with the *p0-PUCCH-Id* value corresponding to q_u and with the *closedLoopIndex* value corresponding to l ; otherwise, $l = 0$

- Else,

$$- \quad g_{b,f,c}(0,l) = \Delta P_{\text{rampup},b,f,c} + \delta_{\text{msg2},b,f,c}, \text{ where}$$

$\delta_{\text{msg2},b,f,c}$ is the TPC command indicated in the random access response grant corresponding to the random access preamble transmitted on UL BWP b of carrier f in the serving cell c , and,

if the UE transmits PUCCH,

$$\Delta P_{\text{rampup},b,f,c} = \min \left[\max \left(0, P_{\text{C}_{\text{MAX}},f,c} - (P_{\text{O_PUCCH},b,f,c} + PL_{b,f,c}(q_d) + \Delta_{\text{F_PUCCH}}(F) + \Delta_{\text{TF},b,f,c} + \delta_{\text{msg2},b,f,c}) \right), \Delta P_{\text{rampuprequested},b,f,c} \right]$$

;

otherwise,

$$\Delta P_{\text{rampup},b,f,c} = \min \left[\max \left(0, P_{\text{C}_{\text{MAX}},f,c} - (P_{\text{O_PUCCH},b,f,c} + PL_{b,f,c}(q_d)) \right), \Delta P_{\text{rampuprequested},b,f,c} \right] \text{ and } \Delta P_{\text{rampuprequested},b,f,c} \text{ is}$$

provided by higher layers and corresponds to the total power ramp-up requested by higher layers from the first to the last preamble for UL BWP b of carrier f of primary cell c , and $\Delta_{\text{F_PUCCH}}(F)$ corresponds to PUCCH format 0 or PUCCH format 1.

- If the UE has reached $P_{\text{C}_{\text{MAX}},f,c}(i)$ for UL BWP b of carrier f of primary cell c , the UE does not accumulate positive TPC commands for UL BWP b of carrier f of primary cell c .
- If the UE has reached minimum power for UL BWP b of carrier f of primary cell c , the UE does not accumulate negative TPC commands for UL BWP b of carrier f of primary cell c .

Table 7.2.1-1: Mapping of TPC Command Field in DCI format 1_0 or DCI format 1_1 or DCI format 2_2 having CRC parity bits scrambled by TPC-PUCCH-RNTI to accumulated $\delta_{\text{PUCCH},b,f,c}$ values

•	TPC Command Field	•	Accumulated $\delta_{\text{PUCCH},b,f,c}$ [dB]
★	0	★	-1
★	1	★	0
★	2	★	1
★	3	★	3

7.3 Sounding reference signals

For SRS, the linear value $\hat{P}_{\text{SRS},b,f,c}(i, q_s, l)$ of the transmit power $P_{\text{SRS},b,f,c}(i, q_s, l)$ on UL BWP b of carrier f of serving cell c is split equally across the configured antenna ports for SRS. The UL BWP b is the active UL BWP.

7.3.1 UE behaviour

If a UE transmits SRS on UL BWP b of carrier f of serving cell c using SRS power control adjustment state with index l , the UE determines the SRS transmission power $P_{\text{SRS},b,f,c}(i, q_s, l)$ in SRS transmission period i as

$$P_{\text{SRS},b,f,c}(i, q_s, l) = \min \left\{ P_{\text{CMAX},f,c}(i), P_{\text{O_SRS},b,f,c}(q_s) + 10 \log_{10} (2^{\mu} \cdot M_{\text{SRS},b,f,c}(i)) + \alpha_{\text{SRS},b,f,c}(q_s) \cdot PL_{b,f,c}(q_d) + h_{b,f,c}(i, l) \right\} \text{ [dBm]}$$

where,

- $P_{\text{CMAX},f,c}(i)$ is the configured UE transmit power defined in [8, TS 38.101-1] and [8-2, TS38.101-2] for carrier f of serving cell c in SRS transmission period i .
- $P_{\text{O_SRS},b,f,c}(q_s)$ is provided by higher layer parameter $p0$ for UL BWP b of carrier f of serving cell c and SRS resource set q_s provided by higher layer parameters *SRS-ResourceSet* and *SRS-ResourceSetId*.
- $M_{\text{SRS},b,f,c}(i)$ is the SRS bandwidth expressed in number of resource blocks for SRS transmission period i on UL BWP b of carrier f of serving cell c and μ is defined in [4, TS 38.211].
- $\alpha_{\text{SRS},b,f,c}(q_s)$ is provided by higher layer parameter *alpha* for UL BWP b of carrier f of serving cell c and SRS resource set q_s .
- $PL_{b,f,c}(q_d)$ is a downlink path-loss estimate in dB calculated by the UE using reference signal (RS) index q_d for a DL BWP that is paired with UL BWP b of carrier f of serving cell c and SRS resource set q_s [6, TS 38.214]. The RS index q_d is provided by higher layer parameter *pathlossReferenceRS* associated with the SRS resource set q_s and is either a higher layer parameter *ssb-Index* providing a SS/PBCH block index or a higher layer parameter *csi-RS-Index* providing a CSI-RS resource index.
- For the SRS power control adjustment state for UL BWP b of carrier f of serving cell c and SRS transmission period i
 - $h_{b,f,c}(i, l) = f_{b,f,c}(i, l)$, where $f_{b,f,c}(i, l)$ is the current PUSCH power control adjustment state as described in Subclause 7.1.1, if higher layer parameter *srs-PowerControlAdjustmentStates* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions; or
 - $h_{b,f,c}(i) = h_{b,f,c}(i-1) + \delta_{\text{SRS},b,f,c}(i - K_{\text{SRS}})$ if the UE is not configured for PUSCH transmissions on UL BWP b of carrier f of serving cell c , or if higher layer parameter *srs-PowerControlAdjustmentStates* indicates a separate power control adjustment state between SRS transmissions and PUSCH transmissions, and if accumulation is enabled based on the parameter *tpc-Accumulation* provided by higher layers, where $\delta_{\text{SRS},b,f,c}(i - K_{\text{SRS}})$ is jointly coded with other TPC commands in a PDCCH with DCI format 2_3, as described in Subclause 11.4, that is last

received by the UE prior to the SRS transmission and accumulative values of $\delta_{\text{SRS},b,f,c}(i - K_{\text{SRS}})$ are provided in Table 7.1.1-1, where

- $\delta_{\text{SRS},b,f,c}(i - K_{\text{SRS}}) = 0$ dB if the UE does not detect a TPC command for serving cell c .
- If the UE has reached $P_{\text{CMAX},f,c}(i)$ for UL BWP b of carrier f of serving cell c , the UE does not accumulate corresponding positive TPC commands.
- If UE has reached minimum power for UL BWP b of carrier f of serving cell c , the UE does not accumulate corresponding negative TPC commands.
- A UE resets accumulation for UL BWP b of carrier f of serving cell c
 - When $P_{\text{O_SRS},b,f,c}(q_s)$ value is changed by higher layers;
 - When $\alpha_{\text{SRS},b,f,c}(q_s)$ value is changed by higher layers.
- $h_{b,f,c}(0) = 0$ is the first value after reset of accumulation.
- If $P_{\text{O_SRS},b,f,c}(q_s)$ value is received by higher layers,
 - $h_{b,f,c}(0) = 0$
- Else,
- $h_{b,f,c}(0) = \Delta P_{\text{rampup},b,f,c} + \delta_{\text{msg2},b,f,c}$, where

$\delta_{\text{msg2},b,f,c}$ is the TPC command indicated in the random access response grant corresponding to the random access preamble transmitted on UL BWP b of carrier f of the serving cell c , and

$$\Delta P_{\text{rampup},b,f,c} = \min \left[\max \left(0, P_{\text{CMAX},f,c} - \left(P_{\text{O_SRS},b,f,c}(q_s) + 10 \log_{10}(2^{\mu} \cdot M_{\text{SRS},b,f,c}(i)) + \alpha_{\text{SRS},b,f,c}(q_s) \cdot PL_{b,f,c}(q_d) \right) \right), \Delta P_{\text{rampuprequested},b,f,c} \right];$$

and $\Delta P_{\text{rampuprequested},b,f,c}$ is provided by higher layers and corresponds to the total power ramp-up requested by higher layers from the first to the last preamble for UL BWP b of carrier f of serving cell c .

- $h_{b,f,c}(i) = \delta_{\text{SRS},b,f,c}(i - K_{\text{SRS}})$ if the UE is not configured for PUSCH transmissions on UL BWP b of carrier f of serving cell c , or if higher layer parameter *srs-PowerControlAdjustmentStates* indicates a separate power control adjustment state between SRS transmissions and PUSCH transmissions, and if accumulation is not enabled based on the higher layer parameter *tpc-Accumulation*, and the UE detects a DCI format 2_3 for a SRS transmission period i , where absolute values of $\delta_{\text{SRS},b,f,c}(i - K_{\text{SRS}})$ are provided in Table 7.1.1-1
- $h_{b,f,c}(i) = h_{b,f,c}(i - 1)$ for a SRS transmission period i where the UE does not detect a DCI format 2_3 for UL BWP b of carrier f of serving cell c .
- if higher layer parameter *srs-PowerControlAdjustmentStates* indicates a same power control adjustment state for SRS transmissions and PUSCH transmissions, the update of the power control adjustment state for SRS

transmission period i occurs at the beginning of each SRS resource in the SRS resource set q_s ; otherwise, the update of the power control adjustment state SRS transmission period i occurs at the beginning of the first transmitted SRS resource in the SRS resource set q_s .

<...>

7.7 Power headroom report

The types of UE power headroom reports are the following. A type 1 UE power headroom PH that is valid for PUSCH transmission period i on UL BWP b of carrier f of serving cell c . A type 3 UE power headroom PH that is valid for SRS transmission period i on UL BWP b of carrier f of serving cell c .

If the UE is configured with a SCG,

- For computing power headroom for cells belonging to MCG, the term 'serving cell' in this subclause refers to serving cell belonging to the MCG.
- For computing power headroom for cells belonging to SCG, the term 'serving cell' in this subclause refers to serving cell belonging to the SCG. The term 'primary cell' in this subclause refers to the PSCell of the SCG.

If the UE is configured with a PUCCH-SCell,

- For computing power headroom for cells belonging to primary PUCCH group, the term 'serving cell' in this subclause refers to serving cell belonging to the primary PUCCH group.
- For computing power headroom for cells belonging to secondary PUCCH group, the term 'serving cell' in this subclause refers to serving cell belonging to the secondary PUCCH group. The term 'primary cell' in this subclause refers to the PUCCH-SCell of the secondary PUCCH group.

7.7.1 Type 1 PH Report

If a UE transmits PUSCH in PUSCH transmission period i on active UL BWP b of carrier f of serving cell c , the UE computes a power headroom for a Type 1 report as

$$PH_{\text{type1},b,f,c}(i,j,q_d,l) = P_{\text{CMAX},f,c}(i) - \left\{ P_{\text{O_PUSCH},b,f,c}(j) + 10 \log_{10} (2^{\mu} \cdot M_{\text{RB},b,f,c}^{\text{PUSCH}}(i)) + \alpha_{b,f,c}(j) \cdot PL_{b,f,c}(q_d) + \Delta_{\text{TF},b,f,c}(i) + f_{b,f,c}(i,l) \right\} \text{ [dB]}$$

where $P_{\text{CMAX},f,c}(i)$, $P_{\text{O_PUSCH},b,f,c}(j)$, $M_{\text{RB},b,f,c}^{\text{PUSCH}}(i)$, $\alpha_{b,f,c}(j)$, $PL_{b,f,c}(q_d)$, $\Delta_{\text{TF},b,f,c}(i)$ and $f_{b,f,c}(i,l)$ are defined in Subclause 7.1.1.

If the UE does not transmit PUSCH in PUSCH transmission period i on UL BWP b of carrier f of serving cell c , the UE computes a power headroom for a Type 1 report as

$$PH_{\text{type1},b,f,c}(i,j,q_d,l) = \tilde{P}_{\text{CMAX},f,c}(i) - \left\{ P_{\text{O_PUSCH},b,f,c}(j) + \alpha_{b,f,c}(j) \cdot PL_{b,f,c}(q_d) + f_{b,f,c}(i,l) \right\} \text{ [dB]}$$

where $\tilde{P}_{\text{CMAX},f,c}(i)$ is computed assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB. ΔT_C =0dB.

MPR, A-MPR, P-MPR and ΔT_C are defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2].

The remaining parameters are defined in Subclause 7.1.1 where $P_{\text{O_PUSCH},b,f,c}(j)$ and $\alpha_{b,f,c}(j)$ are provided from $p0\text{-PUSCH-AlphaSetId} = 0$ for the UL BWP b of carrier f of serving

cell c , $PL_{b,f,c}(q_d)$ is obtained using $PathlossReferenceRS-Id = 0$, and $l = 0$.

7.7.2 Type 2 PH report

This subclause is reserved.

7.7.3 Type 3 PH Report

If a UE transmits SRS in a SRS transmission period i on active UL BWP b of carrier f of serving cell c and the UE is not configured for PUSCH transmissions on carrier f of serving cell c , the UE computes a power headroom for a Type 3 report as

$$PH_{type3,b,f,c}(i, q_s, l) = P_{C_{MAX,f,c}}(i) - \left\{ P_{O_SRS,b,f,c}(q_s) + 10 \log_{10}(2^{\mu} \cdot M_{SRS,b,f,c}(i)) + \alpha_{SRS,b,f,c}(q_s) \cdot PL_{b,f,c}(q_d) + h_{b,f,c}(i, l) \right\} \text{ [dB]}$$

where $P_{C_{MAX,f,c}}(i)$, $P_{O_SRS,b,f,c}(q_s)$, $M_{SRS,b,f,c}(i)$, $\alpha_{SRS,b,f,c}(q_s)$, $PL_{b,f,c}(q_d)$ and $h_{b,f,c}(i, l)$ are defined in Subclause 7.3.1.

If the UE does not transmit SRS in SRS transmission period i on UL BWP b of carrier f of serving cell c , and the UE is not configured for PUSCH transmissions on UL BWP b of carrier f of serving cell c , the UE computes power headroom for a Type 3 report as

$$PH_{type3,b,f,c}(i, q_s, l) = \tilde{P}_{C_{MAX,f,c}}(i) - \left\{ P_{O_SRS,b,f,c}(q_s) + \alpha_{SRS,b,f,c}(q_s) \cdot PL_{b,f,c}(q_d) + h_{b,f,c}(i, l) \right\} \text{ [dB]}$$

where q_s is a SRS resource set corresponding to $SRS-ResourceSetId = 0$ and

$P_{O_SRS,b,f,c}(q_s)$, $\alpha_{SRS,b,f,c}(q_s)$, $PL_{b,f,c}(q_d)$ and $h_{b,f,c}(i, l)$ are defined in Subclause 7.3.1 with corresponding values obtained from $SRS-ResourceSetId = 0$ and $l = 0$. $\tilde{P}_{C_{MAX,f,c}}(i)$ is

computed assuming MPR=0dB, A-MPR=0dB, P-MPR=0dB and $\Delta T_C = 0$ dB. MPR, A-MPR, P-MPR and ΔT_C are defined in [8-1, TS 38.101-1] and [8-2, TS38.101-2].

PHR trigger comprises comparison between previous pathloss value and a current pathloss value. More detail about PHR triggering and reporting are quoted below [11].

5.4.6 Power Headroom Reporting

The Power Headroom reporting procedure is used to provide the serving gNB with information about the difference between the nominal UE maximum transmit power and the estimated power for UL-SCH transmission per activated Serving Cell and also with information about the difference between the nominal UE maximum power and the estimated power for UL-SCH and PUCCH transmission on SpCell and PUCCH SCell.

RRC controls Power Headroom reporting by configuring the following parameters:

- *phr-PeriodicTimer*;
- *phr-ProhibitTimer*;
- *phr-Tx-PowerFactorChange*;

- *phr-Type2PCell*;
- *phr-Type2OtherCell*;
- *phr-ModeOtherCG*;
- *multiplePHR*.

A Power Headroom Report (PHR) shall be triggered if any of the following events occur:

- *phr-ProhibitTimer* expires or has expired and the path loss has changed more than *phr-Tx-PowerFactorChange* dB for at least one activated Serving Cell of any MAC entity which is used as a pathloss reference since the last transmission of a PHR in this MAC entity when the MAC entity has UL resources for new transmission;
- *phr-PeriodicTimer* expires;
- upon configuration or reconfiguration of the power headroom reporting functionality by upper layers, which is not used to disable the function;
- activation of an SCell of any MAC entity with configured uplink;
- addition of the PSCell;
- *phr-ProhibitTimer* expires or has expired, when the MAC entity has UL resources for new transmission, and the following is true for any of the activated Serving Cells of any MAC entity with configured uplink:
 - there are UL resources allocated for transmission or there is a PUCCH transmission on this cell, and the required power backoff due to power management (as allowed by P_{MPR_c} as specified in TS 38.101 [10]) for this cell has changed more than *phr-Tx-PowerFactorChange* dB since the last transmission of a PHR when the MAC entity had UL resources allocated for transmission or PUCCH transmission on this cell.

NOTE: The MAC entity should avoid triggering a PHR when the required power backoff due to power management decreases only temporarily (e.g. for up to a few tens of milliseconds) and it should avoid reflecting such temporary decrease in the values of $P_{\text{CMAX},c}/\text{PH}$ when a PHR is triggered by other triggering conditions.

If the MAC entity has UL resources allocated for new transmission the MAC entity shall:

- 1> if it is the first UL resource allocated for a new transmission since the last MAC reset:
 - 2> start *periodicPHR-Timer*;
- 1> if the Power Headroom reporting procedure determines that at least one PHR has been triggered and not cancelled, and;
 - 1> if the allocated UL resources can accommodate the MAC CE for PHR which the MAC entity is configured to transmit, plus its subheader, as a result of logical channel prioritization:
 - 2> if *multiplePHR* is configured:
 - 3> for each activated Serving Cell with configured uplink associated with any MAC entity:
 - 4> obtain the value of the Type 1 or Type 3 power headroom for the corresponding uplink carrier;
 - 4> if this MAC entity has UL resources allocated for transmission on this Serving Cell; or
 - 4> if the other MAC entity, if configured, has UL resources allocated for transmission on this Serving Cell and *phr-ModeOtherCG* is set to real by upper layers:
 - 5> obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer.

- 3> if *phr-Type2PCell* is configured:
 - 4> obtain the value of the Type 2 power headroom for the PCell;
 - 4> obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer.
- 3> if *phr-Type2OtherCell* is configured:
 - 4> if PUCCH SCell is configured:
 - 5> obtain the value of the Type 2 power headroom for the PUCCH SCell.
 - 4> else (i.e. other CG is configured):
 - 5> obtain the value of the Type 2 power headroom for the SpCell of the other MAC entity.
 - 4> obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer.
- 3> instruct the Multiplexing and Assembly procedure to generate and transmit a PHR MAC CE according to configured *ServCellIndex* and the PUCCH(s) for the MAC entity as defined in subclause 6.1.3.9 based on the values reported by the physical layer.
- 2> else (i.e. Single Entry PHR format is used):
 - 3> obtain the value of the Type 1 or Type 3 power headroom from the physical layer for the corresponding uplink carrier of the PCell;
 - 3> obtain the value for the corresponding $P_{\text{CMAX},c}$ field from the physical layer;
 - 3> instruct the Multiplexing and Assembly procedure to generate and transmit a PHR MAC CE as defined in subclause 6.1.3.8 based on the value reported by the physical layer.
- 2> start or restart *periodicPHR-Timer*;
- 2> start or restart *prohibitPHR-Timer*;
- 2> cancel all triggered PHR(s).

Description of the inventions

Any two or more than two of the following paragraphs, (sub)-bullets, points, actions, or claims described in each invention may be combined logically, reasonably, and properly to form a specific method.

Any sentence, paragraph, (sub)-bullet, point, action, or claim described in each of the following invention(s) may be implemented independently and separately to form a specific method. Dependency, e.g. “based on”, “more specifically”, or etc., in the following invention(s) is just one possible embodiment which would not restrict the specific method.

Issue:

As mentioned in the background, there are several trigger of power headroom report, e.g. pathloss change, timer expiring. When transmissions are performed with narrow, the beam(s) used for transmission may be changed frequently, e.g., due to blockage or scheduling flexibility. However, if the triggering is too often while the power situation is unchanged, unnecessary power headroom report would be generated and included without providing base station additional information than what has been provided. On the other hand, if the power status has changed while no power

headroom report is triggered, base station may not make correct decision for scheduling since up-to date information is not provided. For example, pathloss derived from different beam may be different such that when the scheduled beam changes from one beam to another beam, pathloss difference may exceed the threshold and a power headroom report is triggered. However, the channel condition within each beam may be similar and the report may not be very helpful. On the other hand, even if the pathloss is kept similar, it is possible that channel condition for a beam has been changing a lot while a report would not be triggered. The above analysis can also be applied to the case where UE use more than one beam for transmission. Another factor which may have impact on power headroom triggering is power control algorithm. It is possible that the power control is applied on a per UE basis, e.g. UE would transmits on different beams with similar power level and one control loop is maintained. Alternatively, power control can apply on a per UE beam/TRP beam/TRP basis, e.g. power control for each UE beam is controlled independently and multiple control loops are maintained. Still alternatively, it is also possible that power control for certain UE beams is controlled in a similar way, e.g. as a group, and power control for some other UE beams is controlled in another way, e.g. as another group. An example of group is that UE beams associated with a same TRP belong to the same group. Another example of group is that UE beams associated with a same base station beam or TRP beam belong to the same group. The triggering of power headroom would need to take the aspects into account as well.

When there are multiple pathloss references configured for a UE, so that there would be multiple pathloss values available (for a given time or for a given slot). How to design properly regarding choosing pathloss values for pathloss change comparison need to be taken care. With properly design, PHR trigger results from pathloss change comparison could be more efficient.

The above issue could be described as 1. How to determine “a previous pathloss value, e.g. associated with a PHR” and/or how to determine a current pathloss value when UE determine PHR is triggered due to pathloss or not. Note that determine a previous pathloss value, e.g. associated with a PHR” may comprise determine pathloss value and/or determine which PHR is the associated PHR. For example, the issue could be illustrated by Fig.2. Assume 4 RSs, RS A, RS B, RS C RS D are configured as pathloss reference in Fig.2. As shown in Figure 2, which of a3, b3, c3, d3 is used as a pathloss value for pathloss change determination (e.g. served as x) need to be solved. For example, how to select x from a3, b3, c3, d3? Besides, PHR 2 is the last PHR before PHR1, is PHR1 of PHR2 considered as a PHR whose pathloss value are used for pathloss comparison?

If PHR 2 is considered as the PHR for pathloss comparison, e.g. x-y is considered as pathloss change, which of a2, b2, c2, d2 are used as pathloss change determination, e.g. served as y.

If PHR 1 is considered as the PHR for pathloss comparison, e.g. x-z is considered as pathloss change, which of a1, b1, c1, d1 are used as pathloss change determination, e.g. served as 1.

Note that this application is applicable for a case when UE is not configured with a secondary cell (SCell), e.g. for single cell

Note that this application is applicable for a case when UE is configured with at least one secondary cell (SCell), e.g. for the case of multiple cells, for the case of carrier aggregation or for the case of dual connectivity

Note that the pathloss reference could be configured for PUSCH and/or PUCCH and/or SRS.

Note that the PHR is for PUSCH and/or PUSCH+PUCCH and/or SRS.

Solution:

A first concept of this invention is that a power headroom report would be triggered due to change of pathloss for a specific UE beam or a set of UE beams larger than a threshold. UE may determine whether the pathloss of the specific UE beam or the set of UE beams has changed if the specific UE beam or the set of UE beams is scheduled for transmission. UE does not determine whether the pathloss of the specific UE beam or the set of UE beams has changed if the specific beam or the set of beams is not scheduled for transmission. Change of the pathloss is derived from comparison between current pathloss for the specific UE beam or the set of UE beams and previous pathloss for the specific UE beam or the set of UE beams. Comparison for pathloss change may be done for a same UE beam or a same set of UE beam.

A second concept of this invention is that a power headroom report would be triggered due to change of pathloss associated with a TRP beam, a set of TRP beams, or a TRP larger than a threshold. UE may determine whether the pathloss has changed if a transmission associated with the TRP beam, the set of TRP beams, or the TRP is scheduled. UE does not determine whether the pathloss has changed if a transmission associated with the TRP beam, the set of TRP beams, or the TRP is not scheduled. Change of the pathloss is derived from comparison between current pathloss associated with the TRP beam, the set of TRP beams, or the TRP and previous pathloss associated with the TRP beam, the set of TRP beams, or the TRP.

A third concept of this invention is that a power headroom report would be triggered due to change (or addition or activation) of serving TRP(s), change (or addition or activation) of serving TRP beam(s), change (or addition or activation) of candidate TRP beam(s), or activation (or addition) of a UE beam.

In one example, if pathloss of a specific UE beam or a set of UE beams has changed more than a threshold, a power headroom report would be triggered. Power headroom report may not be triggered if pathloss change is due to change of UE beam or set of UE beams.

The power headroom report may include power headroom for the specific UE beam or the set of UE beams. Alternatively, the power headroom report would include power headroom for all UE beams. Alternatively, the power headroom report would include power headroom for any combination of UE beam(s) within all UE beams. More specifically, a subset of combination of UE beam(s) can be configured to report. More specifically, the subset of combination of UE beam(s) can be linked to the specific UE beam or set of UE beams. More specifically, the subset of combination of UE beam(s) includes UE beam which is not the specific UE beam. More specifically, the subset of combination of UE beam(s) includes UE beam which is not within the subset of UE beams.

The set of UE beams may be UE beams associated with a TRP. Alternatively, the set of UE beams may be UE beams associated with a TRP or base station beam. Preferably, the set of UE beams is configured by a base station.

In one example, power headroom for a specific UE beam is derived based on UE power status of transmission on the specific UE beam. More specifically, the power headroom for the specific UE beam is a difference between a UE calculated transmission power for the specific beam and a maximum transmission power on the specific beam.

In one example, power headroom for a set of UE beams is derived based on UE power status of transmission on the set of UE beams. More specifically, the power headroom for the set of UE beams is a difference between a UE calculated transmission power for the set of beams and a maximum transmission power on the set of beams.

Preferably, the power control is per UE. Alternatively, the power control is per beam. Alternatively, the power control is per beam group/beam set. Alternatively, the power control is per beam combination.

In another embodiment, UE triggers power headroom report for a group of UE beams based on a same first condition. Preferably, the group of UE beams is a subset of UE beams that can be generated by the UE. Preferably, triggering of power headroom report for another group of UE beams would be based on a second condition. Preferably, the power headroom report includes power headroom of each UE beam within the group. Preferably, the power headroom report includes power headroom of any combination of UE beam(s) within the group. More specifically, a subset of the any combinations of UE beam(s) is configured to be included in the power headroom report. Preferably, the first condition is pathloss of a UE beam within the group has changed more than a threshold. Preferably, the first condition is pathloss of a combination of UE beams within the group has changed more than a threshold. Preferably, power headroom report is not triggered if pathloss change is due to change of UE beam or set of UE beams. Preferably, the comparison for pathloss change is done for a same UE beam or a same set of UE beam. Preferably, the first condition is checked if at least one UE beam within the group of UE beams is scheduled for transmission. Preferably, the first condition is not checked if none of UE beam within the group of UE beams is scheduled for transmission. Preferably, the first condition is checked if a specific UE beam or a specific beam combination within the group of UE beams is scheduled for transmission. Preferably, the first condition is not checked if a specific UE beam or a specific beam combination within the group of UE beams is not scheduled for transmission. Preferably, the group of UE beams are UE beams associated with a TRP. Preferably, the group of UE beams are UE beams associated with a TRP or base station beam. Preferably, the group of UE beams is configured by a base station.

Preferably, power headroom for the specific UE beam is derived based on UE power status of transmission on the specific UE beam. More specifically, the power headroom for the specific UE beam is a difference between a UE calculated transmission power for the specific beam and a maximum transmission power on the specific beam.

Preferably, power headroom for a set of UE beams is derived based on UE power status of transmission on the set of UE beams. More specifically, the power headroom for the set of UE beams is a difference between a UE calculated transmission power for the set of beams

and a maximum transmission power on the set of beams.

Preferably, the power control is per UE. Preferably, the power control is per beam.

Preferably, the power control is per beam group/beam set. Preferably, the power control is per beam combination.

Per beam and/or per beam combination power headroom is reported from a UE to a base station. More specifically, UE calculates power headroom for each beam and/or each beam combination. Preferably, power headroom of a beam and/or beam combination used to carry the power headroom is calculated based on real transmission power. Preferably, power headroom of a beam and/or beam combination which is not used to carry the power headroom is calculated assuming a same transmission is performed on the beam and/or beam combination. Preferably, power headroom of a beam and/or beam combination which is not used to carry the power headroom is calculated assuming some predefined parameter, e.g. virtual PH is reported. Preferably, base station indicates power headroom of which beam is reported. Preferably, base station indicates power headroom of which beam combination is reported. Preferably, UE selects power headroom of which beam is reported. More specifically, UE selects beam(s) with largest power headroom(s) to report power headroom. Preferably, UE report power headroom together with an indicator associated with a corresponding beam. Preferably, UE selects power headroom of which beam combination is reported. More specifically, UE selects beam combination(s) with largest power headroom(s) to report power headroom. Preferably, UE report power headroom together with an indicator associated with a corresponding beam combination.

In any of the above embodiment, pathloss of a UE beam is derived from DL signal measured on the UE beam. Preferably, the DL signal is transmitted on multiple TRP/ base station beam(s). More specifically, the multiple TRP/ base station beam(s) are associated with the UE beam.

In any of the above embodiment, pathloss of a set of UE beams is derived from DL signal measured on the set of UE beams. Preferably, the DL signal is transmitted on multiple TRP/ base station beam(s). More specifically, the multiple TRP/ base station beam(s) are associated with the set of UE beams. Preferably, any or any combinations of following can be the DL signal for pathloss measurement:

- Reference signal for pathloss measurement
- Reference signal for beam management
- Reference signal for channel state information measurement
- Reference signal for mobility management
- Reference signal for demodulation
- Beam reference signal

- Demodulation reference signal for a control channel (e.g. an uplink grant for reporting power headroom)
- Demodulation reference signal for a data channel
- Channel state information reference signal
- Synchronization signal

For determining a current pathloss value, e.g. x in Fig2, the following alternative are listed:

1. a pathloss value derived from pathloss reference used for power control and/or deriving power headroom value, e.g. using c3 in Fig2 as RS C is used as reference.
2. a pathloss value derived from pathloss reference which is used for power control and/or deriving power headroom value in the last PHR, e.g. b3 as RS B is used as reference in the last PHR
3. a largest pathloss value
4. a smallest pathloss value
5. a pathloss value derived from pathloss reference which is used for deriving a previous pathloss value for pathloss change determination
6. a pathloss value derived from a specific pathloss reference
7. a pathloss value derived from a pathloss reference configured or indicated for pathloss comparison
8. a pathloss value derived from a pathloss reference with a smallest or largest RS id
9. a pathloss value derived from a pathloss reference with a smallest entry(e.g. 0) or largest entry (e.g. 3) of pathloss reference configuration

For determining a previous pathloss value, e.g. y or z in Fig2, the following alternative are listed:

- a. a pathloss value derived from pathloss reference used for power control and/or deriving power headroom value for last PHR, e.g. using b2 in Fig2 as RS B is used as reference for last PHR.
- b. a pathloss value derived from pathloss reference used for power control and/or deriving power headroom value for last PHR which is derived based on a pathloss reference which is used for PUSCH when pathloss change comparison is done (for), e.g. using c1 in Fig2 as RS C is used as reference for PUSCH1 and PHR 1 has the same used pathloss reference as PUSCH1.
- c. a pathloss value derived from pathloss reference which is used for power control and/or deriving power headroom value for PUSCH when pathloss change comparison is done (for), e.g. c2 in Fig.2 as RS c is used as reference in the PUSCH 1
- d. a largest pathloss value

- e. a smallest pathloss value
- f. a pathloss value derived from pathloss reference which is used for deriving a current pathloss value for pathloss change determination
- g. a pathloss value derived from a specific pathloss reference
- h. a pathloss value derived from a pathloss reference configured or indicated for pathloss comparison
- i. a pathloss value derived from a pathloss reference with a smallest or largest RS id
- j. a pathloss value derived from a pathloss reference with a smallest entry(e.g. 0) or largest entry (e.g. 3) of pathloss reference configuration

Any of alternative 1~9 and alternative a~j above can form a new embodiment. The embodiments determine a previous pathloss value and a current pathloss value. Pathloss change can be performed by comparison between the previous pathloss value and the current pathloss value.

In any of alternative 1~9 or alternative a~j, the UE may use a different pathloss reference for power control and/or deriving power headroom than a pathloss reference for pathloss change comparison. UE does not use a pathloss value which is used for power control and/or deriving power headroom for pathloss change comparison.

The UE uses another pathloss value derived from another pathloss reference for pathloss change.

In any of alternative 1~9 or alternative a~j, the UE may compare pathloss value between a first pathloss value and a second pathloss value, wherein the first pathloss is used for a PUSCH transmission where pathloss change comparison is done for and the second pathloss value is used for a PHR wherein the PHR and the PUSCH use a same pathloss reference.

The UE does not use pathloss value from the last PHR, while use pathloss value from earlier PHR.

A first pathloss value from alternative 1~9 and a second pathloss value from alternative a~j are used to derive a pathloss change.

A UE determines whether a PHR is triggered based on whether the pathloss change is more than a threshold.

The UE decides whether to report PHR accordingly. E.g. subject to whether UL resource is sufficient or not.

The UE is configured with a single cell, e.g. Primary cell (PCell).

Alt.1 Pathloss reference(s) used for pathloss change same as pathloss reference for power control or power headroom. For example, pathloss change is compared between c3 and b2

In this alternative, the pathloss reference(s) used for pathloss change determination follows the pathloss reference for power control or power headroom. This alternative is less preferable as pathloss change can be compared among different pathloss references such that the resulting pathloss change doesn't reflect the real channel quality change for the UE, which means the original design principle of detecting pathloss change borrowed from LTE is violated.

Alt.2 Pathloss reference during last PHR transmission is determined based on "currently used reference" For example, pathloss change is compared between c3 and c2

In this alternative, x is not a constant pathloss reference while would depend on what is a currently used reference when the pathloss comparison is made. For this alternative, pathloss change is compared among pathloss values from a same pathloss reference, such the pathloss change could capture the real channel variation.

Alt3. "last PHR transmission " is PHR using the same reference as "currently used reference". For example, pathloss change is compared between c3 and c1

In this alternative, to use pathloss value in the last PHR with the same pathloss reference as what is a currently used reference when the pathloss comparison is made for pathloss change determination. Note that although the basis for comparison is not pathloss reference from a fixed time occasion, this alternative allows pathloss comparison to be done for a same pathloss reference similar as Alt.2.

Alt.4 Pathloss references used for pathloss change determination same as that in last PHR transmission, For example, pathloss change is compared between b3 and b2

For this alternative, the pathloss reference used for pathloss change determination is the same one used in the last PHR transmission. Similar as Alt.2, pathloss change is compared among pathloss values from a same pathloss reference, such the pathloss change could capture the real channel variation.

Alt.5 Specify a predefined rule to select pathloss references used for pathloss change determination One example of predefined rule could be the strongest pathloss reference for a given instance, i.e. the pathloss reference with least pathloss value. Similar as Alt.1, this alternative suffers from comparing pathloss among different pathloss references. One potential drawback of this alternative is that pathloss reference for power control/PHR and pathloss reference for pathloss change are totally decoupled.

Part of any of Alt1~Alt5 and part of any of Alt.1~5 can form a new embodiment or method

Details of various embodiments are described below:

1. A method, comprising:
A UE performs uplink transmission with UE beam(s),
a power headroom report would be triggered due to change of pathloss for a specific UE beam or a set of UE beams larger than a threshold
2. Based on bullet 1, UE determine whether the pathloss of the specific UE beam or the set of UE beams has changed if the specific UE beam or the set of UE beams is scheduled for transmission.
3. Based on bullet 1 or 2, UE does not determine whether the pathloss of the specific UE beam or the set of UE beams has changed if the specific beam or the set of beams is not scheduled for transmission.
4. Based on bullet 1 to 3, change of the pathloss is derived from comparison between current pathloss for the specific UE beam or the set of UE beams and previous pathloss for the specific UE beam or the set of UE beams.
5. Based on any of bullet 1 to 4, comparison for pathloss change may be done for a same UE beam or a same set of UE beam.
6. Based on any of bullet 1 to 5, power headroom report is triggered if pathloss change is due to change of UE beam or set of UE beams.
7. A method of a UE, comprising:

a power headroom report would be triggered due to change of pathloss associated with a TRP beam, a set of TRP beams, or a TRP larger than a threshold
8. A method of a UE, comprising:
a power headroom report would be triggered due to change (or addition or activation) of serving TRP(s), change (or addition or activation) of serving TRP beam(s), change (or addition or activation) of candidate TRP beam(s), or activation (or addition) of a UE beam.
9. Based on bullet 7 or 8, the UE performs uplink transmission with UE beam(s)
10. Based on any of bullet 7 to 9, the UE may determine whether the pathloss has changed if a transmission associated with the TRP beam, the set of TRP beams, or the TRP is scheduled.
11. Based on any of bullet 7 to 10, the UE does not determine whether the pathloss has changed if a transmission associated with the TRP beam, the set of TRP beams, or the TRP is not scheduled.
12. Based on any of bullet 7 to 11, Change of the pathloss is derived from comparison between current pathloss associated with the TRP beam, the set of TRP beams, or the TRP and previous pathloss associated with the TRP beam, the set of TRP beams, or the TRP.
13. Based on any of bullet 1 to 6, the power headroom report includes power headroom for the specific UE beam or the set of UE beams.
14. Based on any of bullet 7 to 12, the power headroom report includes power headroom for a specific UE beam or a set of UE beams.
15. Based on any of bullet 1 to 12, the power headroom report includes power headroom for all UE

beams

16. Based on any of bullet 1 to 12, the power headroom report includes power headroom for any combination of UE beam(s) within all UE beams.
17. Based on bullet 16, a subset of combination of UE beam(s) can be configured to report.
18. Based on any of bullet 1 to 6, the set of UE beams are UE beams associated with a TRP.
19. Based on any of bullet 1 to 6, the set of UE beams are UE beams associated with a TRP or base station beam.
20. Based on any of 1 to 6, the set of UE beams is configured by a base station.
21. Based on any of bullet 1 to 6, 13 to 20, power headroom for the specific UE beam is derived based on UE power status of transmission on the specific UE beam.
22. Based on bullet 21, the power headroom for the specific UE beam is a difference between a UE calculated transmission power for the specific beam and a maximum transmission power on the specific beam.
23. Based on any of bullet 1 to 6, 13 to 20, power headroom for the set of UE beams is derived based on UE power status of transmission on the set of UE beams.
24. Based on bullet 23, the power headroom for the set of UE beams is a difference between a UE calculated transmission power for the set of beams and a maximum transmission power on the set of beams.
25. Based on any of bullet 1 to 24, power control is per UE.
26. Based on any of bullet 1 to 24, power control is per beam.
27. Based on any of bullet 1 to 24, power control is per beam group/beam set.
28. Based on any of bullet 1 to 24, power control is per beam combination.
29. A method of a UE, comprising:
the UE performs uplink transmission with UE beam(s);
the UE determines whether to trigger power headroom report for a first group of UE beam(s) based on a first condition;
the UE determines whether to trigger power headroom report for a second group of UE beam(s) based on a second condition.
30. Based on bullet 29, the first group of UE beams is a subset of UE beams that can be generated by the UE.
31. Based on any of bullet 29 to 30, the power headroom report includes power headroom of each UE beam within the group.
32. Based on any of bullet 29 to 30, the power headroom report includes power headroom of any combination of UE beam(s) within the group.
33. Based on bullet 32, a subset of the any combinations of UE beam(s) is configured to be included in the power headroom report.
34. Based on any of bullet 29 to 33, the first condition is pathloss of a UE beam within the first

group has changed more than a threshold.

35. Based on any of bullet 29 to 34, the second condition is pathloss of a UE beam within the second group has changed more than a threshold.

36. Based on any of bullet 29 to 35, the first condition is checked if at least one UE beam within the first group of UE beams is scheduled for transmission.

37. Based on any of bullet 29 to 36, the first condition is not checked if none of UE beam within the first group of UE beams is scheduled for transmission.

38. Based on any of bullet 29 to 37, the first condition is checked if a specific UE beam or a specific beam combination within the first group of UE beams is scheduled for transmission.

39. Based on any of bullet 29 to 37, the first condition is not checked if a specific UE beam or a specific beam combination within the first group of UE beams is not scheduled for transmission.

40. Based on any of bullet 29 to 39, the first group of UE beams are UE beams associated with a TRP.

41. Based on any of bullet 29 to 39, the first group of UE beams are UE beams associated with a TRP or base station beam.

42. Based on any of bullet 29 to 39, the first group of UE beams is configured by a base station.

1. A method for a user equipment (UE), the method comprising:

using multiple beams for transmission; and

triggering, by the UE, a power headroom report due to a change of a pathloss being larger than a threshold, wherein the pathloss is associated with a specific beam or a set of beams.

2. The method of claim 1, further comprising:

determining, by the UE, whether the pathloss has changed if a transmission associated with the specific beam or the set of beams is scheduled.

3. The method of claim 1, wherein the specific beam is a specific UE beam or a specific transmission/reception point (TRP) beam.

4. The method of claim 1, wherein the set of beams is a set of UE beams or a set of TRP beams.

5. The method of claim 1, wherein the set of beams is associated with a same TRP beam, a same set of TRP beams, or a same TRP.

6. The method of claim 1, wherein the change of pathloss is derived from a comparison of a same UE beam or a same set of UE beams.

7. The method of claim 1, wherein a change of the pathloss is derived from a comparison

- between a current pathloss value, associated with the specific beam or the set of beams, and a previous pathloss value, associated with the specific beam or the set of beams.
8. The method of claim 1, wherein the pathloss is derived from a downlink signal measured on the specific beam or measured on the set of beams.
9. A method for a user equipment (UE), the method comprising:
determining, by the UE, whether to trigger a power headroom report for a first group of multiple UE beams based on a first condition;
determining, by the UE, whether to trigger a power headroom report for a second group of the multiple UE beams based on a second condition;
triggering, by the UE, the power headroom report for the first group if the first condition is fulfilled; and
triggering, by the UE, the power headroom report for the second group if the second condition is fulfilled.
10. The method of claim 9, wherein the first condition is a pathloss having changed more than a threshold for a UE beam within the first group or a combination of UE beams within the first group.
11. The method of claim 9, wherein the second condition is a pathloss having changed more than a threshold for a UE beam within the second group or a combination of UE beams within the second group.
12. The method of claim 9, wherein the first group and the second group are configured by a base station.
13. A User Equipment (UE), comprising:
a control circuit;
a processor installed in the control circuit; and
a memory installed in the control circuit and coupled to the processor;
wherein the processor is configured to execute a program code stored in the memory to:
use multiple beams for transmission; and trigger a power headroom report due to a change of a pathloss being larger than a threshold, wherein the pathloss is associated with a specific beam or a set of beams.
14. The UE of claim 13, wherein the processor is configured to execute the program code stored in the memory to determine whether the pathloss has changed if a transmission associated with the specific beam or the set of beams is scheduled.

15. The UE of claim 13, wherein the specific beam is a specific UE beam or a specific transmission/reception point (TRP) beam.
16. The UE of claim 13, wherein the set of beams is a set of UE beams or a set of TRP beams.
17. The UE of claim 13, wherein the set of beams is associated with a same transmission/reception point (TRP) beam, a same set of TRP beams, or a same TRP.
18. The UE of claim 13, wherein the change of the pathloss is derived from a comparison of a same UE beam or a same set of UE beams.
19. The UE of claim 13, wherein the change of the pathloss is derived from a comparison between a current pathloss value, associated with the specific beam or the set of beams, and a previous pathloss value associated with the specific beam or the set of beams.
20. The UE of claim 13, wherein the pathloss is derived from a downlink signal measured on the specific beam or measured on the set of beams.

Advantage of the invention

PHR trigger could be more efficient, e.g. reflecting UE real channel change..

References:

The following disclosures are hereby incorporated by reference in their entirety.

1. R2-162366, Beam Forming Impacts, Nokia, Alcatel-Lucent.
2. R2-163716, Discussion on terminology of beamforming based high frequency NR, Samsung.
3. R2-162709, Beam support in NR, Intel.
4. R2-162762, Active Mode Mobility in NR: SINR drops in higher frequencies, Ericsson.
5. 3GPP TS 36.213 v14.0.0, "E-UTRA Physical layer procedures (Release 14)."
6. 3GPP TS 36.101 v14.1.0, "E-UTRA User Equipment (UE) radio transmission and reception (Release 14)"
7. 3GPP TS 36.321 v14.0.0, "E-UTRA Medium Access Control (MAC) protocol specification(Release 14)"
8. U.S. Provisional Patent Application Serial No. 62/419,101
9. U.S. Non-Provisional Patent Application Serial No.15/807,165
10. R1-1805795, "CR to TS 38.213 capturing the RAN1#92bis meeting agreements", Samsung
11. TS 38.321 v.15.1.0, "MAC layer specification (Release 15)".

Figures

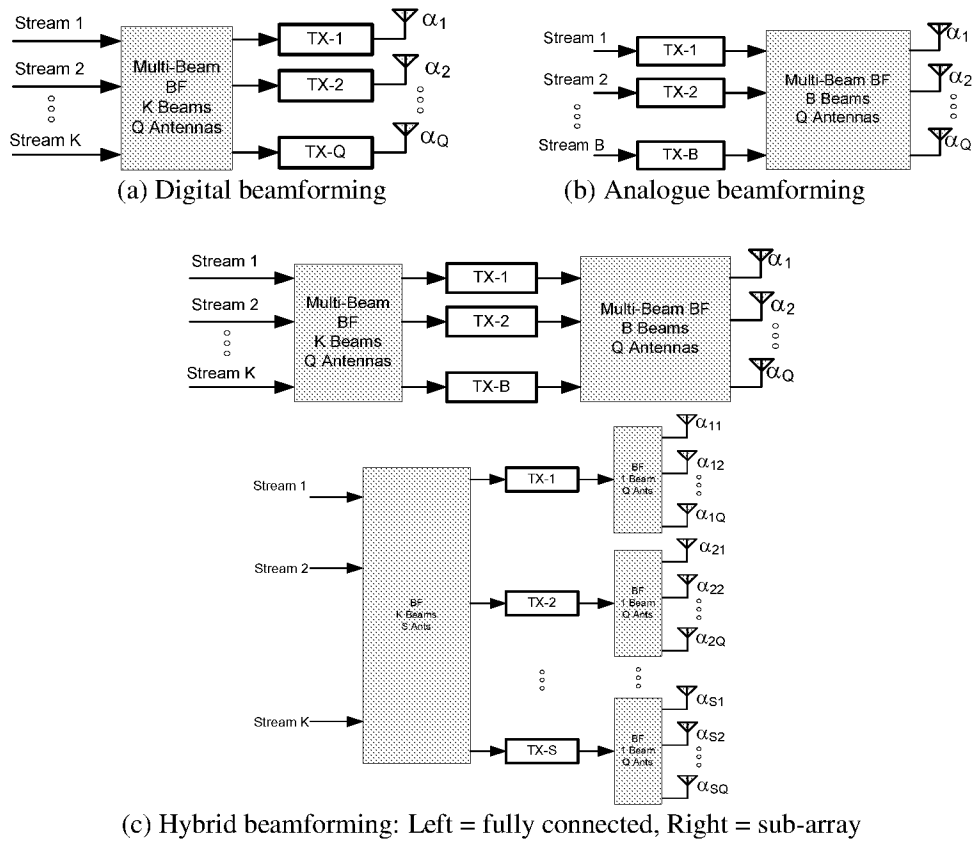


Fig.1

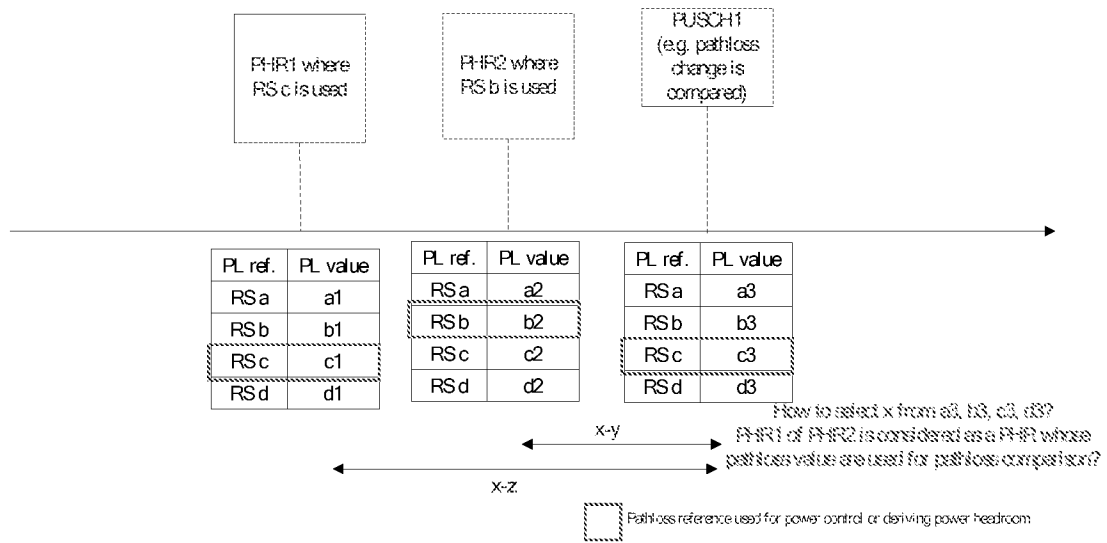
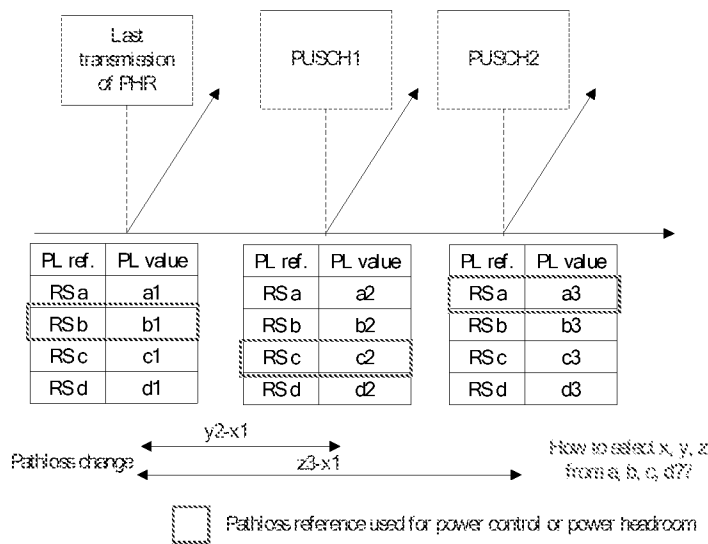
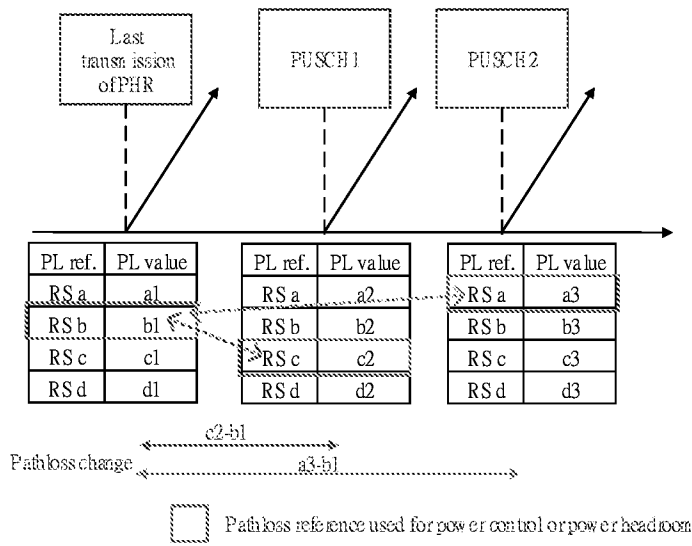


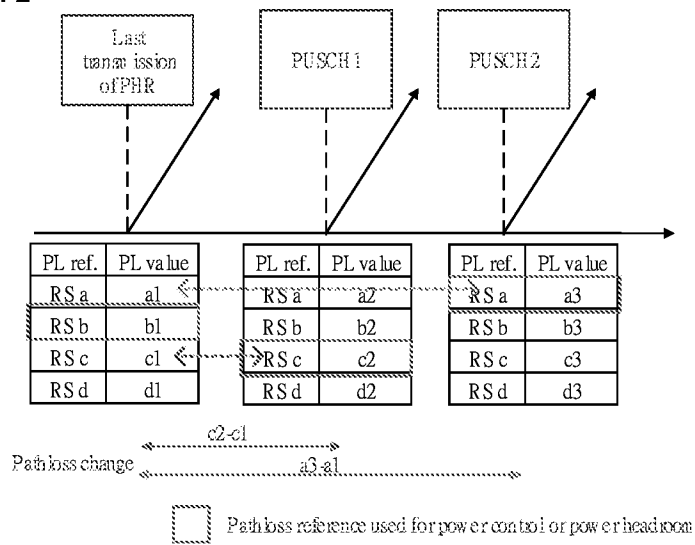
Fig.2



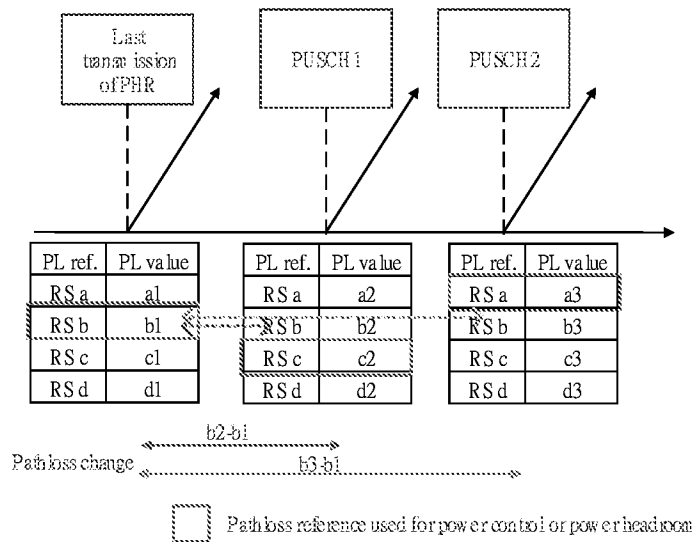
Alt. 1



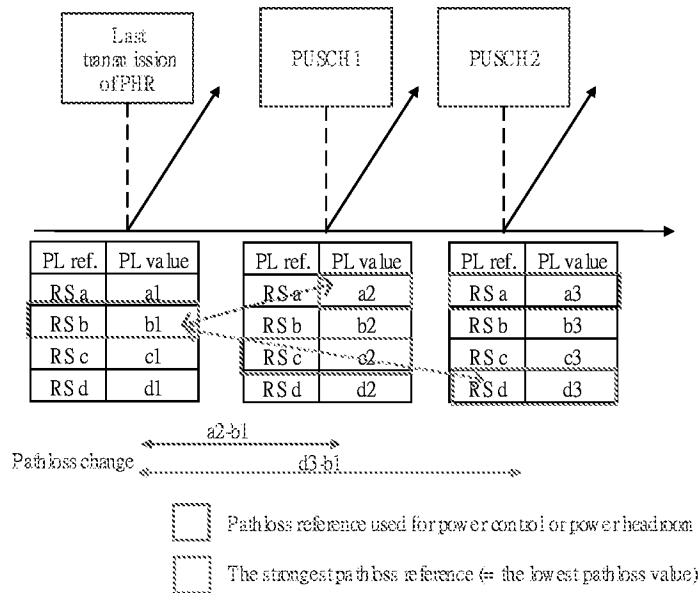
Alt. 2



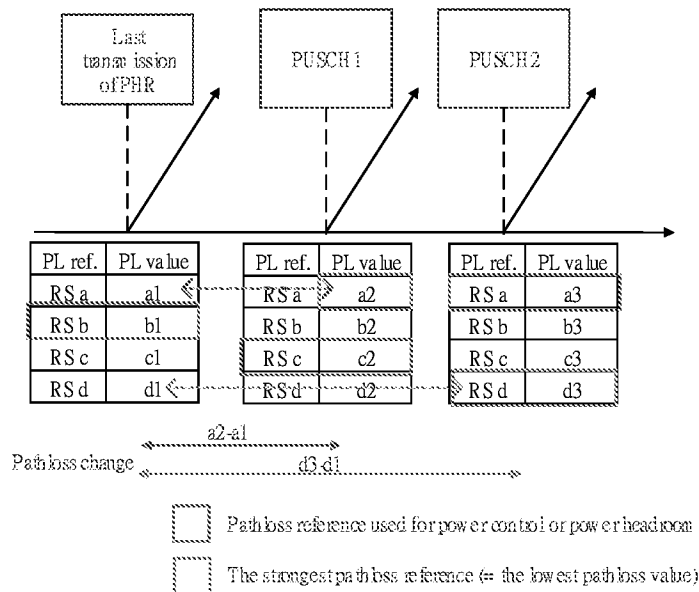
Alt. 3



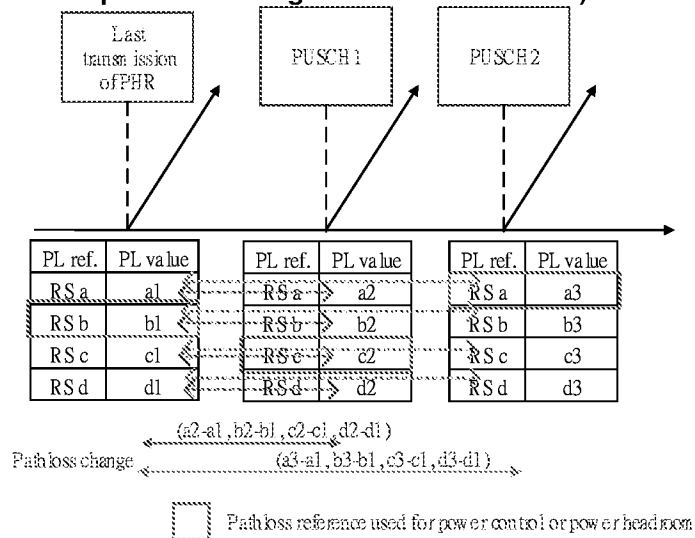
Alt. 4



Alt. 4-2 (This alternative could be derived based on the description of Alt. 4 as well)



Alt. 5 (This alternative is to compare each PL references, and trigger PHR if one of these comparisons is larger than the threshold)



Application and Implementation in Wireless Communication Systems and Devices

The invention(s) described above can be applied to or implemented in exemplary wireless communication systems and devices described below. In addition, the invention(s) is described mainly in the context of the 3GPP architecture reference model. However, it is understood that with the disclosed information, one skilled in the art could easily adapt for use and implement aspects of the invention in a 3GPP2 network architecture as well as in other network architectures.

The exemplary wireless communication systems and devices described below employ a wireless communication system, supporting a broadcast service. Wireless communication systems are widely deployed to provide various types of communication such as voice, data, and so on. These systems may be based on code division multiple access (CDMA), time division multiple access (TDMA), orthogonal frequency division multiple access (OFDMA), 3GPP LTE (Long Term Evolution) wireless access, 3GPP LTE-A (Long Term Evolution Advanced) wireless access, 3GPP2 UMB (Ultra Mobile Broadband), WiMax, or some other modulation techniques.

Figure A1 shows a multiple access wireless communication system according to one embodiment of the invention. An access network 100 (AN) includes multiple antenna groups, one including 104 and 106, another including 108 and 110, and an additional including 112 and 114. In Figure A1, only two antennas are shown for each antenna group, however, more or fewer antennas may be utilized for each antenna group. Access terminal 116 (AT) is in communication with antennas 112 and 114, where antennas 112 and 114 transmit information to access terminal 116 over forward link 120 and receive information from access terminal 116 over reverse link 118. Access terminal (AT) 122 is in communication with antennas 106 and 108, where antennas 106 and 108 transmit information to access terminal (AT) 122 over forward link 126 and receive information from access terminal (AT) 122 over reverse link 124. In a FDD system, communication links 118, 120, 124 and 126 may use different frequency for communication. For example, forward link 120 may use a different frequency than that used by reverse link 118.

Each group of antennas and/or the area in which they are designed to communicate is often referred to as a sector of the access network. In the embodiment, antenna groups each are designed to communicate to access terminals in a sector of the areas covered by access network 100.

In communication over forward links 120 and 126, the transmitting antennas of access network 100 may utilize beamforming in order to improve the signal-to-noise ratio of forward links for the different access terminals 116 and 122. Also, an access network using beamforming to transmit to access terminals scattered randomly through its coverage normally causes less interference to access terminals in neighboring cells than an access network transmitting through a single antenna to all its access terminals.

An access network (AN) may be a fixed station or base station used for communicating with the terminals and may also be referred to as an access point, a Node B, a base station, an enhanced base station, an eNodeB, or some other terminology. An access terminal (AT) may also be called user equipment (UE), a wireless communication device, terminal, access terminal or some other terminology.

Figure A2 is a simplified block diagram of an embodiment of a transmitter system 210 (also known as the access network) and a receiver system 250 (also known as access terminal (AT) or user equipment (UE)) in a MIMO system 200. At the transmitter system 210, traffic data for a number of data streams is provided from a data source 212 to a transmit (TX) data processor 214.

In one embodiment, each data stream is transmitted over a respective transmit antenna. TX data processor 214 formats, codes, and interleaves the traffic data for each data stream based on a particular coding scheme selected for that data stream to provide coded data.

The coded data for each data stream may be multiplexed with pilot data using OFDM techniques. The pilot data is typically a known data pattern that is processed in a known manner and may be used at the receiver system to estimate the channel response. The multiplexed pilot and coded data for each data stream is then modulated (i.e., symbol mapped) based on a particular modulation scheme (e.g., BPSK, QPSK, M-PSK, or M-QAM) selected for that data stream to provide modulation symbols. The data rate, coding, and modulation for each data stream may be determined by instructions performed by processor 230.

The modulation symbols for all data streams are then provided to a TX MIMO processor 220, which may further process the modulation symbols (e.g., for OFDM). TX MIMO processor 220 then provides N_T modulation symbol streams to N_T transmitters (TMTR) 222a through 222t. In certain embodiments, TX MIMO processor 220 applies beamforming weights to the symbols of the data streams and to the antenna from which the symbol is being transmitted.

Each transmitter 222 receives and processes a respective symbol stream to provide one or more analog signals, and further conditions (e.g., amplifies, filters, and upconverts) the analog signals to provide a modulated signal suitable for transmission over the MIMO channel. N_T modulated signals from transmitters 222a through 222t are then transmitted from N_T antennas 224a through 224t, respectively.

At receiver system 250, the transmitted modulated signals are received by N_R antennas 252a through 252r and the received signal from each antenna 252 is provided to a respective receiver (RCVR) 254a through 254r. Each receiver 254 conditions (e.g., filters, amplifies, and downconverts) a respective received signal, digitizes the conditioned signal to provide samples, and further processes the samples to provide a corresponding “received” symbol stream.

An RX data processor 260 then receives and processes the N_R received symbol streams from N_R receivers 254 based on a particular receiver processing technique to provide N_T “detected” symbol streams. The RX data processor 260 then demodulates, deinterleaves, and decodes each detected symbol stream to recover the traffic data for the data stream. The processing by RX data processor 260 is complementary to that performed by TX MIMO processor 220 and TX data processor 214 at transmitter system 210.

A processor 270 periodically determines which pre-coding matrix to use (discussed below). Processor 270 formulates a reverse link message comprising a matrix index portion and a rank value portion.

The reverse link message may comprise various types of information regarding the communication link and/or the received data stream. The reverse link message is then processed by a TX data processor 238, which also receives traffic data for a number of data streams from a data source 236, modulated by a modulator 280, conditioned by transmitters 254a through 254r, and transmitted back to transmitter system 210.

At transmitter system 210, the modulated signals from receiver system 250 are received by antennas 224, conditioned by receivers 222, demodulated by a demodulator 240, and processed by a RX data processor 242 to extract the reverse link message transmitted by the receiver system 250. Processor 230 then determines which pre-coding matrix to use for determining the beamforming weights then processes the extracted message.

Memory 232 may be used to temporarily store some buffered/computational data from 240 or 242 through Processor 230, store some buffered data from 212, or store some specific program codes. And Memory 272 may be used to temporarily store some buffered/computational data from 260 through Processor 270, store some buffered data from 236, or store some specific program codes.

Turning to Figure A3, this figure shows an alternative simplified functional block diagram of a communication device according to one embodiment of the invention. As shown in Figure A3, the

communication device 300 in a wireless communication system can be utilized for realizing the UEs (or ATs) 116 and 122 in Figure A1, and the wireless communications system is preferably the LTE system. The communication device 300 may include an input device 302, an output device 304, a control circuit 306, a central processing unit (CPU) 308, a memory 310, a program code 312, and a transceiver 314. The control circuit 306 executes the program code 312 in the memory 310 through the CPU 308, thereby controlling an operation of the communications device 300. The communications device 300 can receive signals input by a user through the input device 302, such as a keyboard or keypad, and can output images and sounds through the output device 304, such as a monitor or speakers. The transceiver 314 is used to receive and transmit wireless signals, delivering received signals to the control circuit 306, and outputting signals generated by the control circuit 306 wirelessly.

Figure A4 is a simplified block diagram of the program code 312 shown in Figure A3 in accordance with one embodiment of the invention. In this embodiment, the program code 312 includes an application layer 400, a Layer 3 portion 402, and a Layer 2 portion 404, and is coupled to a Layer 1 portion 406. The Layer 3 portion 402 generally performs radio resource control. The Layer 2 portion 404 generally performs link control. The Layer 1 portion 406 generally performs physical connections.

For LTE or LTE-A system, the Layer 2 portion 404 may include a Radio Link Control (RLC) layer and a Medium Access Control (MAC) layer. The Layer 3 portion 402 may include a Radio Resource Control (RRC) layer.

Various aspects of the disclosure have been described above. It should be apparent that the teachings herein may be embodied in a wide variety of forms and that any specific structure, function, or both being disclosed herein is merely representative. Based on the teachings herein one skilled in the art should appreciate that an aspect disclosed herein may be implemented independently of any other aspects and that two or more of these aspects may be combined in various ways. For example, an apparatus may be implemented or a method may be practiced using any number of the aspects set forth herein. In addition, such an apparatus may be implemented or such a method may be practiced using other structure, functionality, or structure and functionality in addition to or other than one or more of the aspects set forth herein. As an example of some of the above concepts, in some aspects concurrent channels may be established based on pulse repetition frequencies. In some aspects concurrent channels may be established based on pulse position or offsets. In some aspects concurrent channels may be established based on time hopping sequences. In some aspects concurrent channels may be established based on pulse repetition frequencies, pulse positions or offsets, and time hopping sequences.

Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

Those of skill would further appreciate that the various illustrative logical blocks, modules, processors, means, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware (e.g., a digital implementation, an analog implementation, or a combination of the two, which may be designed using source coding or some other technique), various forms of program or design code incorporating instructions (which may be referred to herein, for convenience, as “software” or a “software module”), or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may

implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

In addition, the various illustrative logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented within or performed by an integrated circuit ("IC"), an access terminal, or an access point. The IC may comprise a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, electrical components, optical components, mechanical components, or any combination thereof designed to perform the functions described herein, and may execute codes or instructions that reside within the IC, outside of the IC, or both. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

It is understood that any specific order or hierarchy of steps in any disclosed process is an example of a sample approach. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged while remaining within the scope of the present disclosure. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

The steps of a method or algorithm described in connection with the aspects disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module (e.g., including executable instructions and related data) and other data may reside in a data memory such as RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other form of computer-readable storage medium known in the art. A sample storage medium may be coupled to a machine such as, for example, a computer/processor (which may be referred to herein, for convenience, as a "processor") such the processor can read information (e.g., code) from and write information to the storage medium. A sample storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in user equipment. In the alternative, the processor and the storage medium may reside as discrete components in user equipment. Moreover, in some aspects any suitable computer-program product may comprise a computer-readable medium comprising codes relating to one or more of the aspects of the disclosure. In some aspects a computer program product may comprise packaging materials.

While the invention has been described in connection with various aspects, it will be understood that the invention is capable of further modifications. This application is intended to cover any variations, uses or adaptation of the invention following, in general, the principles of the invention, and including such departures from the present disclosure as come within the known and customary practice within the art to which the invention pertains.

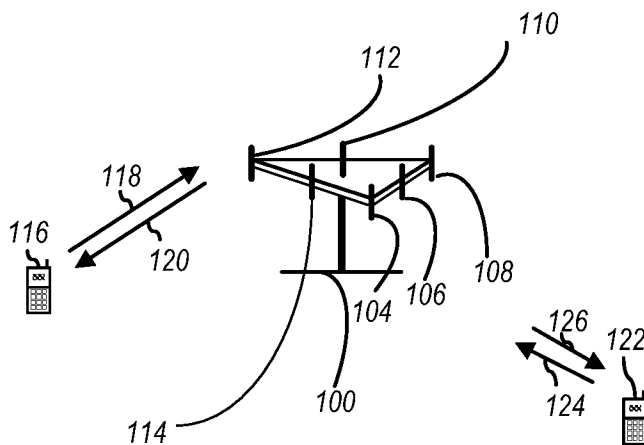


FIG. A1

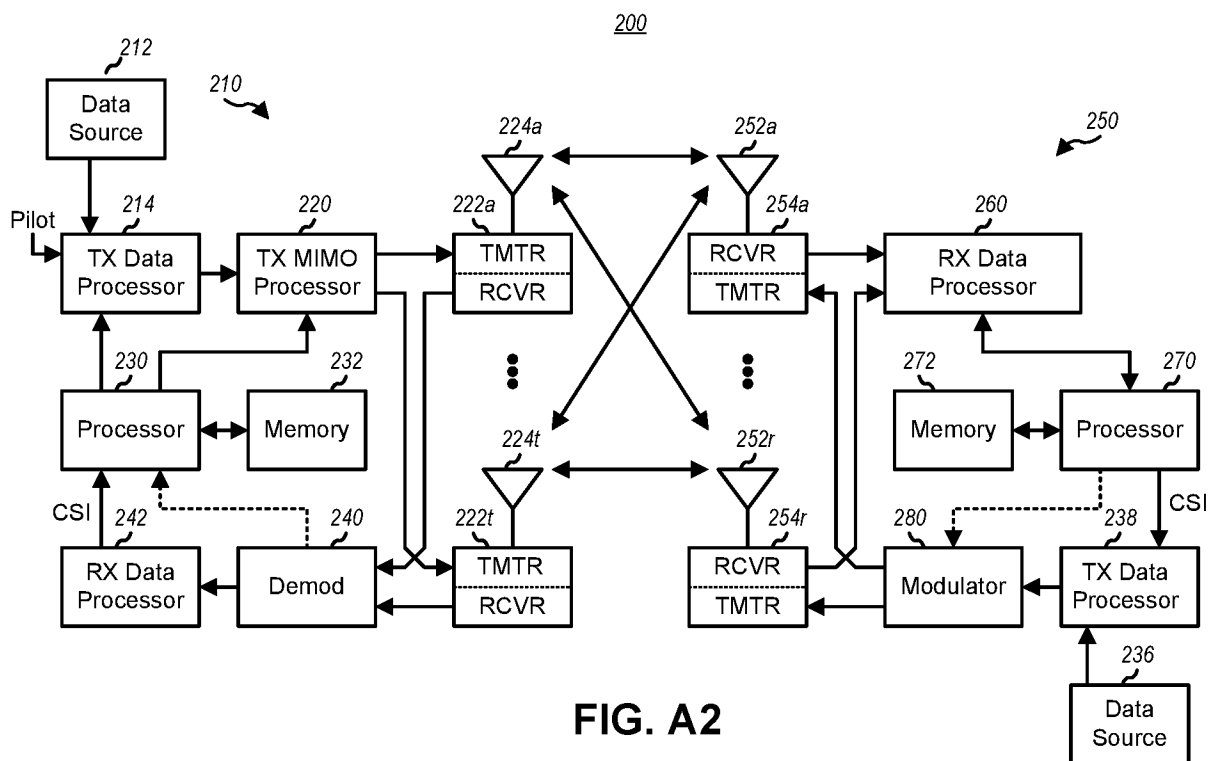


FIG. A2

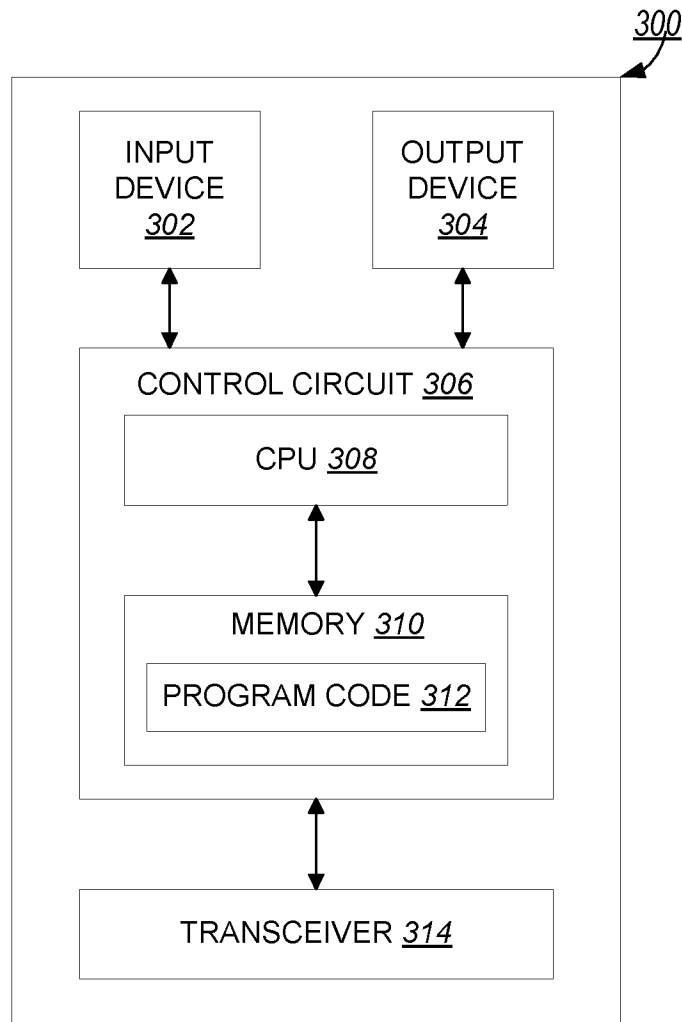


FIG. A3

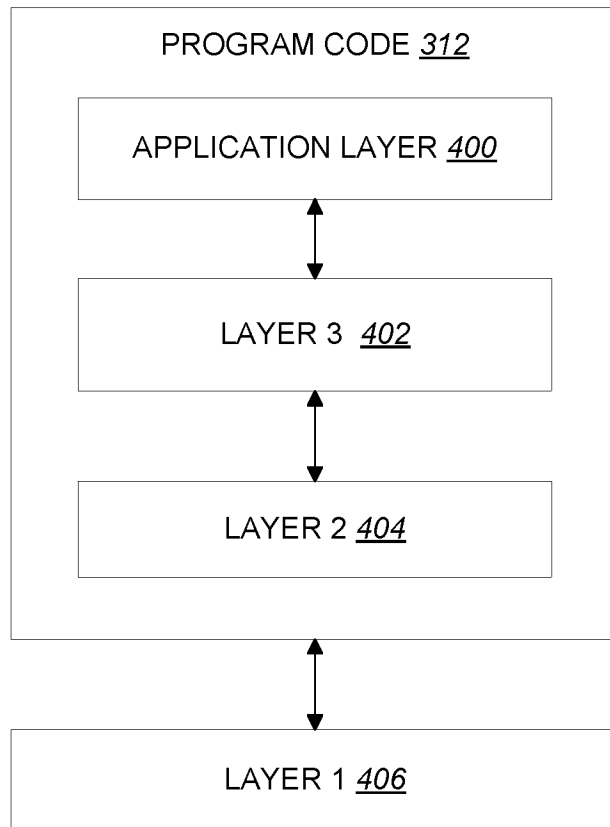


FIG. A4