

DM-RSs may be used in precoding, where the user-specific DM-RSs are also precoded in the same manner as the data. Other use cases for DM-RS exist, for example, estimating the residual interference originating from other users scheduled on the same time and frequency resources in same or different cells.

[0006] In OFDMA, users are allocated a specific number of sub-carriers for a predetermined amount of time. These are referred to as physical resource blocks (PRBs) in the LTE specifications. PRBs have both a time and frequency dimension. The allocation of PRBs is handled by a scheduling function at the 3GPP base station (eNodeB).

[0007] Conventionally, user-specific DM-RSs are transmitted only within the allocated PRBs. This may be seen as a disadvantage as it prevents the UE's channel-estimator from interpolating on the edges of the allocated resource. The lack of interpolation at the edges becomes a limiting factor for the performance of frequency narrow allocations, such as 1-3 PRBs. The edge effect can be minimized (but not fully suppressed) by placing DM-RSs on the edge of the allocated PRBs. However, placing the DM-RSs on the edge increases the DM-RS overhead. Placing the DM-RSs on the edge of the PRB is also a disadvantage, for example, in the case of stacking more PRBs in frequency and/or time, where the DM-RSs located on the edge become somehow redundant.

[0008] PRB bundling in frequency for channel estimation is a solution adopted in the LTE specifications. The channel estimation is performed within 3 consecutive frequency PRBs and the overhead is 12 reference symbols per 1 PRB. Also for low cost machine-type communication (MTC) the channel estimation across multiple subframes in time is possible. While this may be currently sufficient, latency requirements of LTE Pro/5G shorten the TTI, and cannot afford the overhead of 12 reference symbols in 1 PRB. Therefore, the LTE Pro/5G latency requirements may rely on channel interpolation gain suppressing the noise.

BRIEF SUMMARY

[0009] This section is intended to include examples and is not intended to be limiting.

[0009a] In accordance with an aspect, there is provided a method, comprising:

allocating, by a network node, a physical resource block allocation for transmission of
at least one user-specific reference signal; and

transmitting to a user equipment the at least one user-specific reference signal in a pattern, wherein the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal transmitted outside of the physical resource block allocation.

[0009b] In accordance with an aspect, there is provided an apparatus, comprising:
at least one processor; and

at least one memory including computer program code,

the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to perform at least the following:

allocate a physical resource block for transmission of at least one user-specific reference signal; and

transmit to a user equipment the at least one user-specific reference signal in a pattern, wherein the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal transmitted outside of the physical resource block allocation.

[0009c] In accordance with an aspect, there is provided an apparatus, comprising:
means for allocating a physical resource block for transmission of at least one

user-specific reference signal; and means for transmitting to a user equipment the at least one user-specific reference signal in a pattern, wherein the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal transmitted outside of the physical resource block allocation.

[0009d] In accordance with an aspect, there is provided a method, comprising:

receiving, by a user equipment, at least one user-specific reference signal in a pattern,
and

performing channel estimation based on the at least one user-specific reference signal, wherein at least part of the at least one user-specific reference signal is in a physical resource block allocation of the user equipment and the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal received outside of the physical resource block allocation of said user equipment.

[0009e] In accordance with an aspect, there is provided an apparatus, comprising:
at least one processor; and

at least one memory including computer program code,

the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to perform at least the following:
receive at least one user-specific reference signal in a pattern; and
perform channel estimation based on the at least one user-specific reference signal,
wherein at least part of the at least one user-specific reference signal is in a physical resource block allocation of a user equipment and the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal received outside of the physical resource block allocation of the user equipment.

[0009f] In accordance with an aspect, there is provided the apparatus of, wherein the pattern of the at least one user-specific reference signal of the user equipment overlays another pattern of user-specific reference signals of the user equipment.

[0009g] In accordance with an aspect, there is provided an apparatus, comprising:
means for receiving at least one user-specific reference signal in a pattern; and
means for performing channel estimation based on the at least one user-specific reference signal, wherein at least part of the at least one user-specific reference signal is in a physical resource block allocation of the user equipment and the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signals received outside of the physical resource block allocation.

[0010] In accordance with an exemplary method, a network node, such as an eNB, allocates a PRB allocation for transmission of at least one user-specific RS. The at least one user-specific RS is configured to be transmitted in a pattern. The at least one user-specific RS is transmitted to a UE. The pattern of the at least one user-specific RS includes at least one over-the-edge RS transmitted outside of the PRB allocation.

[0011] The pattern of the at least one user-specific RS may be beyond an edge of the PRB allocated to the UE. Another PRB beyond the edge of the PRB allocation may be

CLAIMS:

1. A method, comprising:
allocating, by a network node, a physical resource block allocation for transmission of
at least one user-specific reference signal; and
transmitting to a user equipment the at least one user-specific reference signal in a
pattern, wherein the pattern of the at least one user-specific reference signal
includes at least one over-the-edge reference signal transmitted outside of the
physical resource block allocation.
2. The method of claim 1, wherein the pattern of the at least one user-specific reference
signal enables channel estimation beyond an edge of the physical resource block
allocated to the user equipment.
3. The method of claim 1, wherein another physical resource block allocation beyond the
edge of the physical resource block allocation is allocated to another user equipment.
4. The method of claim 3, wherein a physical downlink shared channel of said another
user equipment is rate matched around the pattern of the at least one user-specific
reference signal.
5. The method of claim 1, wherein the pattern of the at least one user-specific reference
signal includes at least one in-band reference signal that is within the physical resource
block allocation and at least one over-the-edge reference signal that is outside of the
physical resource block allocation.
6. The method of claim 5, wherein two or more of the at least one over-the-edge reference
signal are uniformly spaced with respect to the at least one in-band reference signal
located within the physical resource block allocation.
7. The method of claim 1, wherein a reference signal at an edge of the physical resource
block allocation is multiplexed if same resource elements are used for the physical

resource block allocation and a physical resource block allocation of a neighboring user equipment.

8. The method of claim 7, wherein the multiplexed reference signal at the edge of the physical resource block allocation results in boosted power of the multiplexed reference signal.
9. The method of any one of claims 1 through 8, where said at least one over-the-edge reference signal transmitted outside of the physical resource block does not overlap with another physical resource block allocated to another user equipment.
10. The method of any one of claims 1 through 8, wherein the pattern of the at least one user-specific reference signal of the user equipment overlays another pattern of user-specific reference signals of the user equipment.
11. An apparatus, comprising:
at least one processor; and
at least one memory including computer program code,
the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to perform at least the following:
allocate a physical resource block for transmission of at least one user-specific reference signal; and
transmit to a user equipment the at least one user-specific reference signal in a pattern,
wherein the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal transmitted outside of the physical resource block allocation.
12. The apparatus of claim 11, wherein the pattern of the at least one user-specific reference signal enables channel estimation beyond an edge of the physical resource block allocated to the user equipment.
13. The apparatus of claim 11, wherein another physical resource block beyond the edge of the physical resource block allocation is allocated to another user equipment.

14. The apparatus of claim 13, wherein a physical downlink shared channel of said another user equipment is rate matched around the pattern of the at least one user-specific reference signal.
15. The apparatus of claim 11, wherein the pattern of the at least one user-specific reference signal includes at least one in-band reference signal that is within the physical resource block allocation and at least one over-the-edge reference signal that is outside of the physical resource block allocation.
16. The apparatus of claim 15, wherein two or more of the at least one over-the-edge reference signal are uniformly spaced with respect to the at least one in-band reference signal located within the physical resource block allocation.
17. The apparatus of claim 11, wherein a reference signal at an edge of the physical resource block allocation is multiplexed if same resource elements are used for the physical resource block allocation and a physical resource block allocation of a neighboring user equipment.
18. The apparatus of claim 17, wherein the multiplexed reference signal at the edge of the physical resource block allocation results in boosted power of the multiplexed reference signal.
19. The apparatus of any one of claims 11 through 18, wherein said at least one over-the-edge reference signal transmitted outside of the physical resource block does not overlap with another physical resource block allocated to another user equipment.
20. The apparatus of any one of claims 11 through 18, wherein the pattern of the at least one user-specific reference signal of the user equipment overlays another pattern of user-specific reference signals of the user equipment.
21. An apparatus, comprising:
means for allocating a physical resource block for transmission of at least one user-specific reference signal; and

means for transmitting to a user equipment the at least one user-specific reference signal in a pattern, wherein the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal transmitted outside of the physical resource block allocation.

22. A method, comprising:
receiving, by a user equipment, at least one user-specific reference signal in a pattern,
and
performing channel estimation based on the at least one user-specific reference signal,
wherein at least part of the at least one user-specific reference signal is in a physical resource block allocation of the user equipment and the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal received outside of the physical resource block allocation of said user equipment.
23. The method of claim 22, wherein the performing comprising performing channel estimation based on pattern of the at least one user-specific reference signal beyond an edge of the physical resource block allocated to the user equipment.
24. The method of claim 22, wherein another physical resource block allocation beyond an edge of the physical resource block allocation is for another user equipment.
25. The method of claim 22, wherein a physical downlink shared channel of said another user equipment is rate matched around the pattern of the at least one user-specific reference signal.
26. The method of claim 22, wherein the pattern of the at least one user-specific reference signal includes at least one in-band reference signal that is within the physical resource block allocation and at least one over-the-edge reference signal that is outside of the physical resource block allocation.

27. The method of claim 26, wherein two or more of the at least one over-the-edge reference signal are uniformly spaced with respect to the at least one in-band reference signal located within the physical resource block allocation.
28. The method of claim 22, wherein a reference signal at an edge of the physical resource block allocation is multiplexed if same resource elements are used for the physical resource block allocation and a physical resource block allocation of a neighboring user equipment.
29. The method of claim 28, wherein the multiplexed reference signal at the edge of the physical resource block allocation results in boosted power of the multiplexed reference signal.
30. The method of any one of claims 22 through 29, wherein said at least one reference signal received outside of the physical resource block allocation does not overlap with another physical resource block of another user equipment.
31. The method of any one of claims 22 through 29, wherein the pattern of the at least one user-specific reference signal of the user equipment overlays another pattern of user-specific reference signals of the user equipment.
32. An apparatus, comprising:
 - at least one processor; and
 - at least one memory including computer program code,the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to perform at least the following:
 - receive at least one user-specific reference signal in a pattern; and
 - perform channel estimation based on the at least one user-specific reference signal, wherein at least part of the at least one user-specific reference signal is in a physical resource block allocation of a user equipment and the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signal received outside of the physical resource block allocation of the user equipment.

33. The apparatus of claim 32, wherein the performing comprising performing channel estimation pattern of the at least one user-specific reference signal beyond an edge of the physical resource block allocated to the user equipment.
34. The apparatus of claim 32, wherein another physical resource block allocation beyond the edge of the physical resource block allocation of the user equipment is for another user equipment.
35. The apparatus of claim 34, wherein a physical downlink shared channel of said another user equipment is rate matched around the pattern of the at least one user-specific reference signal.
36. The apparatus of claim 32, wherein the pattern of the at least one user-specific reference signal includes at least one in-band reference signal that is within the physical resource block allocation and at least one over-the-edge reference signal that is outside of the physical resource block allocation.
37. The apparatus of claim 36, wherein two or more of the at least one over-the-edge reference signal are uniformly spaced with respect to the at least one in-band reference signal located within the physical resource block allocation.
38. The apparatus of claim 32, wherein a reference signal at an edge of the physical resource block allocation is multiplexed if same resource elements are used for the physical resource block allocation and a physical resource block allocation of a neighboring user equipment.
39. The apparatus of claim 38, wherein the multiplexed reference signal at the edge of the physical resource block allocation results in boosted power of the multiplexed reference signal.
40. The apparatus of any one of claims 32 through 39, wherein said at least one over-the-edge reference signal received outside of the physical resource block does not overlap with another physical resource block for another user equipment.

41. The apparatus of any one of claims 32 through 39, wherein the pattern of the at least one user-specific reference signal of the user equipment overlays another pattern of user-specific reference signals of the user equipment.
42. An apparatus, comprising:
means for receiving at least one user-specific reference signal in a pattern; and
means for performing channel estimation based on the at least one user-specific reference signal, wherein at least part of the at least one user-specific reference signal is in a physical resource block allocation of the user equipment and the pattern of the at least one user-specific reference signal includes at least one over-the-edge reference signals received outside of the physical resource block allocation.
43. A computer program comprising program code for executing the method according to any of claims 1 to 8 or 22 to 29.