BEAM ALIGNMENT

Methods for Efficient Alignment of Transmission and Reception Beams

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EXECUTIVE SUMMARY

Billions of user devices are expected to crowd into 5G-Advanced and especially 6G networks in the near future. Due to the exponentially increasing demand for real-time high-volume throughput, it is essential that future communications be carried on narrow "beams" focused on the intended recipient. At the receive end, the recipient can optimize the received signal by aiming a "reception" beam toward the transmitter. Beams enhance the signal level at the recipient, while saving transmission power and minimizing interference with other receivers. Transmission and reception beams greatly reduce background noise, and save power by focusing the transmitted energy where it is needed. Energy conservation is an increasing priority for base stations, and especially for battery-constrained user devices, mobile users, and IoT devices.

Directional beams must be properly aligned. Current procedures for beam alignment involve extensive scanning and feedback messaging - a significant consumption of time and energy, hardly suitable for the fast-cadence communication demanded of next-generation wireless. What networks need now, are procedures designed to enable base stations and user devices to efficiently align their transmission and reception beams , in real-time, at negligible cost.

Examples detailed below [1] show how a base station can align all the user devices at the same time, by transmitting a special alignment pulse in which the signal varies by angle, all around the base station. Each user device measures the as-received signal, and thereby determines its direction relative to the base station. The user device then informs the base station of its angle. Both uplink and downlink beams are instantly aligned - without scanning. As a further simplification, the base station can list its own latitude and longitude in the system information messages that are periodically broadcast, enabling a prospective user to aim its beam toward the base station right from the start. Mobile user devices, with continually changing alignment conditions, can inform the base station of their planned trajectory upon cell entry, so that the base station can track them as they move along roadways and other predictable trajectories. For further convenience, base stations can measure the signal receptivity throughout the area, boosting unicast power temporarily when someone enters a low-receptivity region. For ultimate efficiency, AI-based algorithms can assist base stations in beam optimization and power control.

By these methods and others detailed below, base stations and user devices can align their beams for optimal communication reliability, with minimal consumption of resource area, minimal transmission energy, and negligible wasted time. Such improvements will be critical to network performance, and hence to user acceptance, in the high-density, high-throughput networking demanded by next-generation market applications.

ALIGNMENT PULSE WITH ANGLE-DEPENDENT PHASE

Networks are seeking a simpler, more efficient way to align the base station beams with individual user devices, and for the user devices to align their beams toward the base station. A new and very efficient way to accomplish mutual beam alignment is a special "phased alignment" pulse, transmitted by the base station, with an angle-dependent phase. The phased alignment pulse can be transmitted all around the base station, but with a phase that varies from 0 to 360 degrees according to the direction. Each user device can determine its direction simply by measuring the phase of the received signal. For accuracy, a second "calibrator" pulse, with a uniform phase in all directions, may be transmitted simultaneously, and each user can compare the two received signal phases, thereby determining the angle while canceling many errors. The user device then reports the received phase, or the corresponding angle, to the base station for mutual beam alignment.

Figure 1 shows a phased alignment pulse schematically. The star is the base station and the diamond is the user device. The bold arrows represent wide overlapping beamlets in eight directions as indicated by the angles A=0, A=45, etc. Each beamlet, with a phase P=0, P=45, ... overlaps and blends with the adjacent beamlets, providing a linear phase-angle response as-received. The base station can also transmit a calibrator pulse, with the same phase in all directions, for comparison. Thus the user device, sitting at an angle of 70 degrees, would measure a net phase of 70 degrees at its location. The user device can then transmit a beamed acknowledgement toward the base station, informing the base station of the received phase or the corresponding angle. The user device and the base station beams thereby become aligned for optimal communication.

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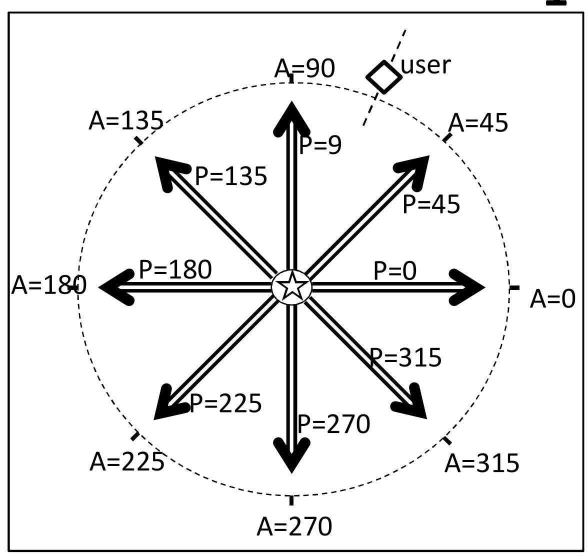

Fig. 1 Phased alignment pulse transmission.

Figure 2 shows how an antenna cluster can generate the phased alignment pulse. A single antenna would have a difficult time trying to emit the full 360-degree phase distribution spatially, but with multiple panels, it is straightforward. Each panel is designed to generate many overlapping beamlets with a pre-programmed phase in a particular direction. For the phased alignment pulse, each panel may be programmed to generate three beamlets in three directions. (This is done by adding the beam production instructions for three overlapping beamlets as shown, each beamlet aimed in a different direction and with a different phase.) A user device receives the blended overlap signal at its location, a weighted average of the beamlet phases, thereby obtaining a phase which is linearly related to the angle. Analog and hybrid antennas can produce a similar composite using overlapping beams.

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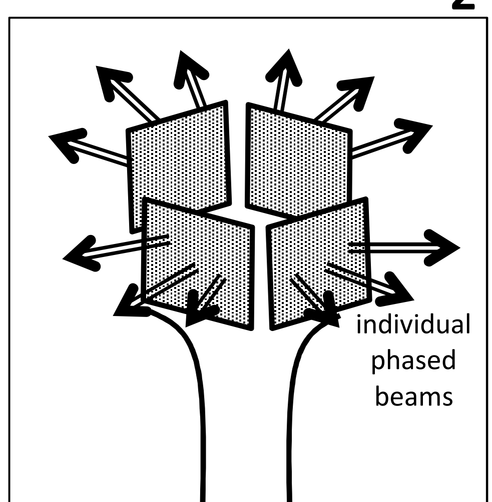

Fig. 2 Beamlets emitted around 360°.

Figure 3 shows how a phased alignment pulse can be constructed from individual beamlets, partially overlapping. A single beamlet is shown in bold. When combined with neighboring beamlets at different angles and phases (8 shown at 45 degree intervals), the blended resultant can closely approximate a linear phase-vs-angle distribution. The user device can measure the phase of the received signal, which is a weighted combination of two blended beamlets, and thereby determine its angle from the net phase received. All of the user devices of the network can be aligned using a single phased alignment pulse, and one calibration pulse. This represents a huge reduction in transmission energy, resource consumption, and time relative to the old beam-scanning technique.

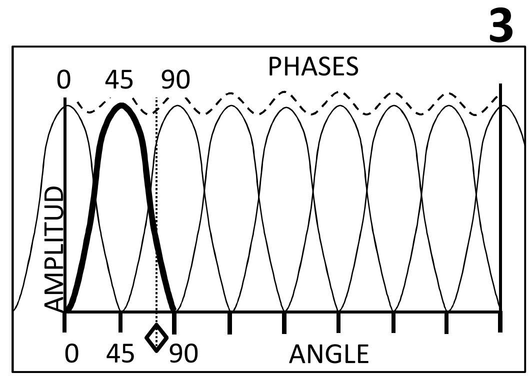

Fig. 3 Each beamlet has different phase.

Figure 4 shows the linear phase vs angle for the beamlets of Fig. 3. With proper adjustment of the shape and spacing of the individual beamlets, the resultant distribution at the user devices can be a linear function of the angle around the base station as shown. In this case, the phase is detected by a user device, sitting at an angle of 70 degrees relative to North, as viewed by the base station. The user compares the received phase to the calibration phase, and thereby determines its alignment angle. The user device can then aim its own transmission and reception beams toward the base station at the detected angle plus 180 degrees.

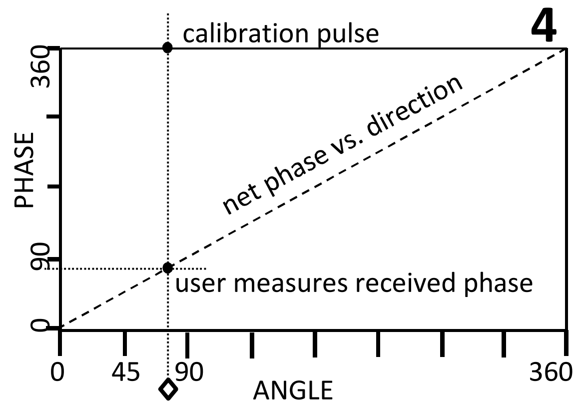

Fig. 4 User measures phase at own location.

Figure 5 shows how the user device can obtain even higher angular resolution with a "vernier" pulse. In this example, the base station emits the alignment and calibrator pulses, plus the vernier pulse. The first pulse is like Fig. 4, a 360-degree phase change in 360 degrees of angle. Then the vernier pulse has a much higher phase progression, in this case 360 degrees of phase in just 90 degrees of angle. All of the user devices in the network can thereby measure their location angle by comparing the received phases of the alignment, calibrator, and vernier pulses. Thus all the users determine their alignment unambiguously, with high precision, from just three transmitted signals, without beam-scanning.

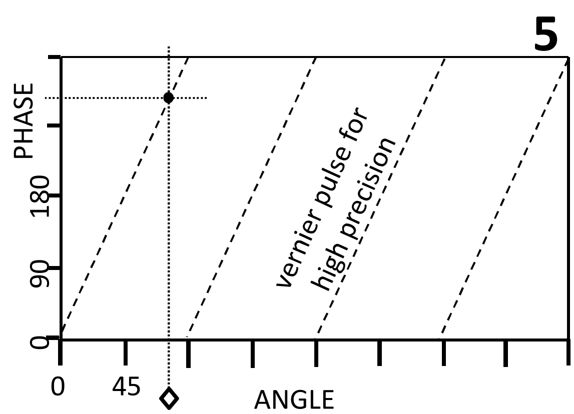

Fig. 5 Vernier pulse has multiple cycles.

Many low-cost wireless devices, such as IoT sensors, have isotropic antennas which are unable to form directional beams at all. Nevertheless, all wireless devices can detect phase quite effectively, and therefore can compare the phase of the calibration and alignment pulses. Each device can then report the angle or phase difference back to the base station as described, so the base station can use its directional beams in communications with those devices thereafter. Even the most basic IoT devices can benefit from the phased alignment beam procedure, by providing location information to the base station.

Value-Chain Analysis: Beam Alignment by Phased Alignment Pulse

For users:

The phased alignment pulse enables users to instantly and precisely align their reception and transmission beams toward the base station antenna, right from the start, and thereby avoid time-consuming and energy-intensive beam scans. The phased alignment pulse, and the simultaneous calibrator and optional vernier pulses, can be transmitted either before or after the SSB message on the broadcast channel. Every user can readily update its alignment angle by checking the periodic broadcast pulses, and hence obtain much better signal quality.

Alignment during initial-access allows new users to receive the SIB1 and other system information messages reliably with high SNR, and also to transmit the RACH preamble and other entry messages on a directed uplink beam, thereby saving energy while avoiding message faulting during the critical initial-access procedure.

Mobile users can update their beam alignment every 20 milliseconds, at zero cost, by checking the phased alignment pulse as they move around. This eliminates the substantial expense of legacy beam scanning procedures.

In summary, the phased alignment pulses allow mobile users to maintain good beam alignment continuously, without beam scanning, at zero cost.

For networks:

Phased beam alignment pulses also benefit networks. They enable the base station to align all the users in a network simultaneously, with a single pulse, instead of laboriously beam-scanning each user individually. The savings in transmitted power and time are enormous. And by avoiding the burden of beam-scanning each individual user, this makes scheduling much easier for the base station, while improving latency and reliability at no cost, other than to simply broadcast three pulses in one OFDM symbol periodically.

Phased beam alignment pulses additionally allow networks to eliminate the wasteful convention of transmitting the SSB message multiple times in different directions, with a different code. Instead, the base station can transmit the SSB just once, along with the phased alignment pulse, thereby saving further energy and freeing up resources for regular communication.

The uplink requires no change, since each user can indicate its alignment direction in the RACH code, as usual. (However, if greater precision is required in 6G, the user can append a short code to its RACH message, specifying its alignment direction with higher precision.)

In addition, enabling the users to align their beams at the very beginning of initial-access provides better reception for receiving the system information messages, thus avoiding false starts and costly delays during the initial entry process.

These substantial benefits greatly outweigh the miniscule cost of actually transmitting the phased alignment pulses.

ALIGNMENT PULSE WITH ANGLE-DEPENDENT AMPLITUDE

The previous example shows how the base station can align beams to all of its user devices with a phased alignment pulse in which the phase varies with angle. In the following method, the alignment pulse has an angle-dependent amplitude instead of phase.

Figure 6A shows the spatial distribution of an alignment pulse that has amplitude varying with angle, in one quadrant. The base station can transmit an alignment pulse with a high amplitude at some angles and a low amplitude at other angles. The user device can measure the amplitude at its location, and determine its angular direction relative to the base station. For disambiguation, the base station can transmit several such pulses, each rotated by various angles.

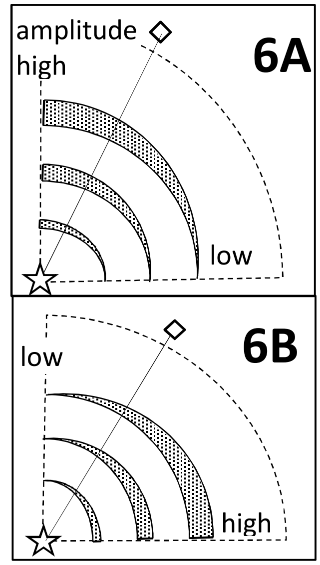

Fig. 6A-B Amplitude varies with angle.

Figure 6B shows a second pulse with a reversed distribution of amplitude versus angle. The user compares the two amplitudes at its location, and thereby determines its angle relative to the base station. Again, multiple transmissions at different angles may be useful, such as at 0 and 90 degrees orientation. Also, the "low" amplitude does not need to be zero. For measurement accuracy, the amplitude could vary from, say, 0.3 to 1.0 times a maximum value. The receiver is expected to know the format.

Figure 7 shows how the transmitter can generate a linear amplitude ramp by transmitting a set of simultaneous overlapping beamlets with different amplitudes, aimed in different directions in one quadrant. The user device measures the received amplitude at its location, which is a blended sum of the beamlet amplitudes, including part of each beamlet that contributes to the user device's received signal.

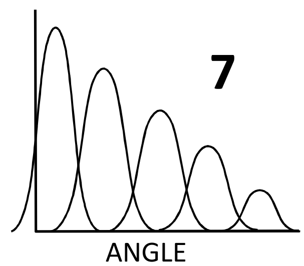

Fig. 7 Amplitude beamlets.

Figure 8 shows the resulting smooth linear distribution of amplitude versus angle in 90 degrees. The base station can transmit a single alignment pulse in which the amplitude varies linearly with the angle, between the low and high values, in a predetermined pattern. User device can calculate its angle from the data, or it can transmit the data to the base station and let the base station calculate the angle. Either way, both the base station and the user device become instantly aligned.

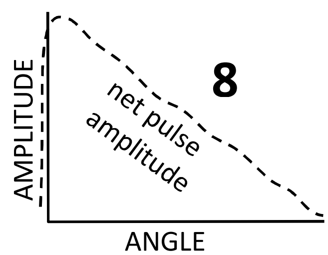

Fig. 8 Linear distribution.

Figure 9 shows how a user device (diamond) can determine its angle relative to the base station by measuring the received amplitudes of two alignment pulses and a calibration pulse. One alignment pulse (short dash) has an amplitude varying from max to min to max, in 360 degrees. The other alignment pulse (long-dash lines) is a vernier pulse that varies from max to min to max every 90 degrees. The calibration pulse (solid line), has the same amplitude in all directions. The user device measures the three received amplitudes (black dots) to determine its angle precisely.

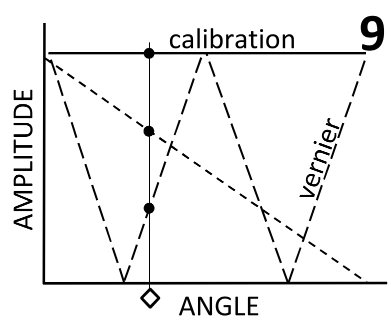

Fig. 9 High resolution vernier.

Value-Chain Analysis: Angle-Dependent Amplitude

For users:

All of the value-added items listed for phased alignment pulses apply equally to the angle-dependent amplitude pulses as well.

For networks:

The network benefits listed above also apply in this case. As stated, these substantial benefits greatly outweigh the miniscule cost of actually transmitting the angle-dependent amplitude pulses.

<u>SSB MESSAGE WITH BASE STATION LOCATION</u>

Mobile user devices often struggle to find an appropriate base station and to initially log on. It would be helpful if the base station indicated its geographical location as early as possible in the initial-access procedure, so that user devices could then communicate using directional beams for the remainder of the registration, and thereafter. The first signal that a prospective user device detects from a base station, is the SSB (synchronization signal block) message that base stations periodically transmit. Three variations are shown for adding the base station location to the SSB.

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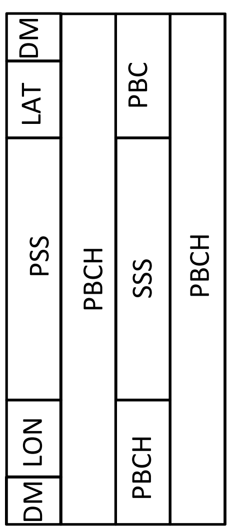

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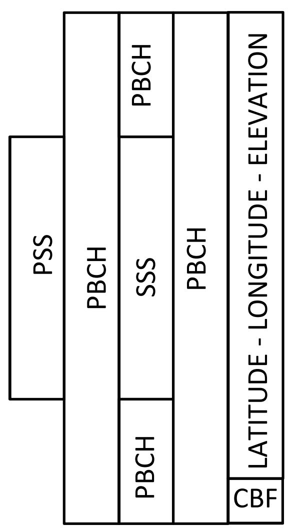

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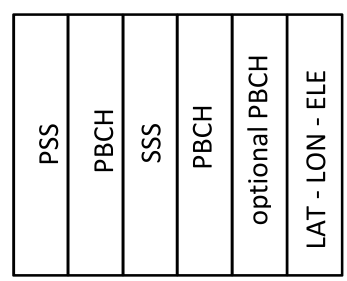

Figure 10 shows a modified SSB message. The SSB normally includes the primary synchronization signal PSS, secondary synchronization signal SSS, and the system information PBCH needed for reception. The modification is to place the latitude and longitude of the base station in the unused portions of the first symbol. To assist first-time users, which may not be synchronized with the base station, two short-form demodulation references DM are also provided. The modulation may be simple BPSK which is relatively robust even pre-synchronization, using the demodulation references for comparison. The receiver then calculates the direction toward the base station from its current position, and aims its reception and transmission beams at the base station. The receiver can also calculate the distance to the base station, and thereby determine how much transmission power would be required for proper reception of the RACH message, thus avoiding a time-consuming power scan with the RACH message.

Figure 11 shows another SSB variation, in which the latitude and longitude, and the antenna elevation, are given in a fifth OFDM symbol. Since this version has the data at the end of the SSB message, the receiver can benefit from the synchronization and formatting provided in the other parts before attempting to demodulate the location data. (This version may be more practical for conventional receivers since it does not rely on demodulating location data before synchronizing.) As an option, the cell-barred flag CBF is also provided, so that the user can jump to another candidate base station if this one is private, without waiting for the subsequent SIB1 message.

Figure 12 shows an alternative version of the modified SSB, adapted to accommodate reduced-capability receivers with lower bandwidth capability. In this version, the location information is placed in the last symbol-time, after the synchronization signals and another "optional" PBCH symbol, if needed for specifying all the network data. Thus the total message size is 5 or 6 symbol-times.

After determining the location of the base station as provided in the SSB, the user device can calculate the angular direction toward the base station relative to geographical North. Then, using an electronic compass or other means to determine the direction of geographical North, the user device can configure its antenna to generate a narrow transmission beam and a narrow reception beam centered on the base station. The user device can then inform the base station of the angle, preferably using the RACH code, as usual. Alternatively, for higher precision, the user device can append its location information or angle information onto the RACH message, or one of the other access messages, or a separate message after registration. Beaming during the initial access procedure enhances the signal levels received by both the user device and the base station during the registration procedure, and in all future communications.

Value-Chain Analysis: Location Indicated in SSB Message

For users:

All of the value-added items listed for phased alignment pulses and angle-dependent amplitude pulses, apply equally to the SSB-location method as well. By indicating the location explicitly, no new analysis procedures are need for user beam alignment, other than calculating the angle from the digital data received. It is very beneficial for new users to align their reception and transmission beams as early in the access procedure as possible.

In addition, users can save time by receiving just a single SSB transmission, thus eliminating the wasted time currently spent listening to a large number of SSB transmissions merely to assess the alignment direction.

The current procedure of informing the base station of the user's alignment direction according to the RACH code can remain as-is. If additional precision is needed, the user can append a bit-level code to the RACH or other initial access message at negligible cost.

When the new user transmits its RACH message, it can adjust the power level according to the distance, and thereby avoid a time-wasting power scan.

Mobile users can continually adjust their alignment angle and power level as they drive around the region, without the need for beam scans or power scans or feedback messages or SRS and CSI messages or any other communication. A major power-waster is eliminated!

For networks:

In addition to the network advantages listed earlier, appending the location data to the SSB message enables the base station to align the users with no changes and no fancy beamforming, other than to simply add one OFDM symbol on the broadcast channel. This is a trivial cost which is vastly overshadowed by the elimination of beam scans and power scans.

The network can also save resources and power by transmitting the SSB only once (per 20 ms) instead of repeatedly transmitting the SSB in different directions.

LINK MAINTENANCE FOR MOBILE USERS

Maintaining beam alignment is at least as important for mobile user devices as for stationary users. However, mobile users have five problems that stationary users do not: (a) the alignment angle changes as the mobile user moves, (b) the directionality changes when the mobile user turns, (c) the Doppler frequency corrections change as the mobile user moves relative the base station, (d) the power requirements change as the distance to the base station changes, and (e) the power requirements also change when the mobile user passes behind an obstruction. The same issues arise when the user is communicating in sidelink to another user.

Figure 13A shows how a mobile user (vehicle) can align its beam with the base station if it knows the location of the base station and geographical North. The user device then informs the base station of the angle. Alternatively, the user informs the base station of the user's location and planned trajectory, so the base station can track the user over time while employing directional downlink beams.

Figure 13B shows how the mobile user device and the base station must both adjust their beams as the user moves, to keep each other in alignment. The adjustment depends not only on the user device's lateral motion, but also on its radial distance from the base station.

Figure 13C shows how the mobile user readjusts its beams when it turns a corner. The mobile user device must continually adjust its beam direction to compensate for its changing direction as well as location.

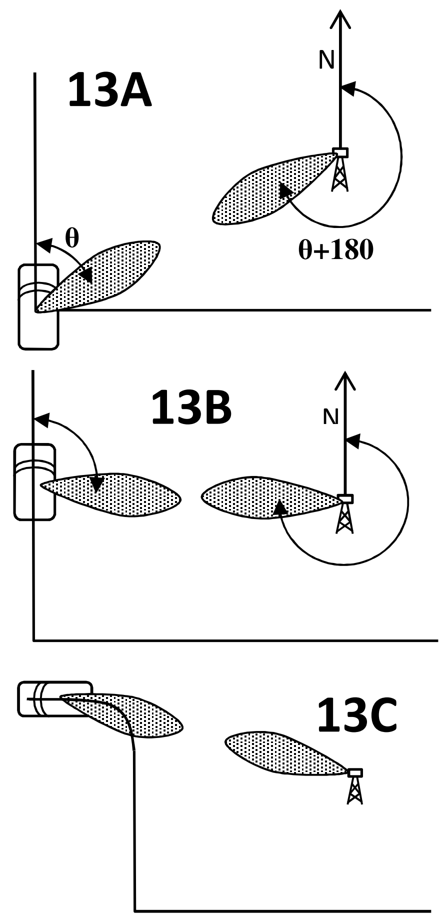

Fig. 13A-B-C: Mobile user keeps beam aimed at base station as it travels.

The mobile user can help the base station maintain beam alignment by telling the base station its location, speed, and direction of travel immediately upon entering the cell. The user device can then update the information whenever it turns or changes speed.

In addition, the base station can keep a map of the area, including roads for vehicles, sidewalks and trails for pedestrians, and so forth. The base station can locate the user's initial position on the map, setting the directional beams and beam power accordingly. The base station can then revise its directional beams and beam power based on the user's planned speed along each road or path, keeping the user in focus without wasting power and resources on unnecessary beam scans. The base station may also account for stop signs and other expected speed and direction changes. For example, the base station can determine, from the user's initial coordinates, which road the user starts on, and then extrapolate the user's time-dependent location along the road as it curves on the map, and thereby keep its beam directed at the mobile user without the need for frequent beam scanning. The user device can update its speed and direction if they change significantly. In a crowded network region with limited available bandwidth, both the mobile user device and the base station can save time and power by calculating the optimal beam directions based on location data, and by updating the locations according to a planned trajectory of the mobile user. They can resort to an old-fashioned beam scan only if required by an unexpected change in the user's motion or other beam-loss event.

A goal of the network is to maintain links even under adverse conditions. First, the base station can measure the receptivity all around its coverage region. Then, whenever a user enters a dead zone, the base station provides extra transmission power to compensate. Result: no more dead zones!

Figure 14A shows a dead zone situation in which a car passes behind a hill. The base station has previously determined that receptivity is low in that region, and how much attenuation it represents. If the base station knows that the mobile user is on the road that passes through the dead zone, and if the base station knows when the mobile user is scheduled to enter and exit the dead zone, then the base station can apply the extra transmission power for reliable communication. The user then gets good reception completely transparently.

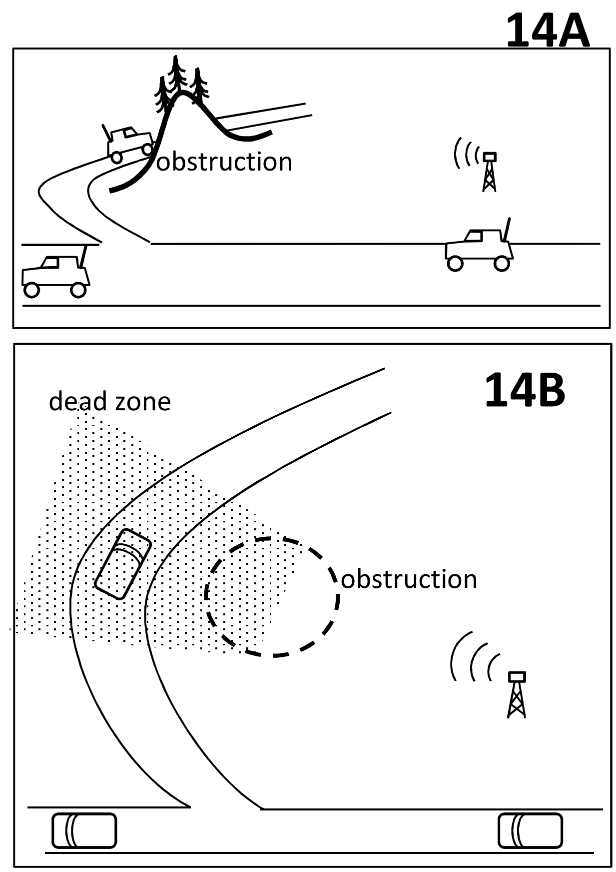

Fig. 14 A-B: A mobile user device in a dead zone. Base station increases power to compensate.

Figure 14B shows a map of the area, in which the base station has measured the attenuation or receptivity at numerous positions along roadways, and possibly other places where pedestrian users go. In this example, the vehicles have informed the base station of their initial locations, speeds, and directions, after which the base station calculates their positions along roadways. When one of them turned onto a side street, it informed the base station of the turn. The base station knows that the street passes through the dead zone, and can then calculate when the user is likely to enter and exit the dead zone based on the user's speed. The base station can thus apply the predetermined additional transmission power to downlink messages for that user during the obstructed interval. The base station is also prepared for a weaker uplink signal, and may take steps to compensate its reception as well, while the user is in the dead zone.

In this way, the base station, in cooperation with each mobile user device, can maintain reception even in adverse locations. No costly beam scanning is needed at any time. Substantially improved network reliability can be provided, at virtually zero cost after the receptivity map has been prepared.

Value-Chain Analysis: Mobile Link Maintenance

For users:

The mobile user can save large amounts of time and energy if it knows the location of the base station's antenna. The mobile user can then automatically adjust its beam direction, Doppler correction, and transmission power according to its orientation, velocity, and distance. These adjustments may be performed transparently to the driver, in real-time, while the vehicle travels throughout to the base station's region.

By performing these corrections based on geometry, the user can ensure continuous signal quality, while avoiding the wasteful beam scans and complex messaging of the current procedures, thereby saving battery time and resources.

And it is completely free.

For networks:

The base station can provide the best communication experience for its users by avoiding the interruptions, poor signal quality, and dropped calls that are inevitable with current alignment protocols. By modeling each user's instantaneous location, the base station can keep beams focused on the user, including mobile users, without the high cost (and scheduling headache) of beam scanning for each mobile device. Since the updating is then effectively real-time, the base station can safely use narrower beams which provide better signal with less power, greatly reducing the background generation problem.

And with the receptivity map, the base station can ensure that each user will enjoy an uninterrupted, high-quality communication experience, by adding extra power when the user passes behind a known obstruction.

The costs are very low - simply measuring the receptivity map. The savings in energy and resource usage more than compensate.

AI APPLIED TO BEAM ALIGNMENT AND POWER

Artificial intelligence can greatly assist in several aspects of beam optimization, including beam alignment and power optimization. Figure 15, for example, shows how a neural net AI model can be trained to recommend the best transmission power level for each downlink message individually, based on three categories of input information (network factors, the message itself including distance to recipient, and the electromagnetic environment). In determining the optimal power setting, a host of complex and competing interests must be balanced, such as avoiding further background noise, yet providing enough transmission power to likely avoid a costly retransmission, while remaining sensitive to the other networks within radio range since they could be adversely affected as well.

The AI model inputs are shown as squares, linked to internal functions or "nodes" (circles) in several layers (only 2 shown), which are finally accumulated as the output prediction (triangle). For training, a "ground truth" is provided, based on an expert network operator's judgement or on the subsequent results of each particular transmission. The AI prediction is compared to the ground truth, and if they differ, certain adjustable parameters in each of the internal functions are incrementally adjusted to bring the prediction more in agreement. When good performance is demonstrated under a wide variety of network, message, and environmental factors, the model is ready for deployment in base stations.

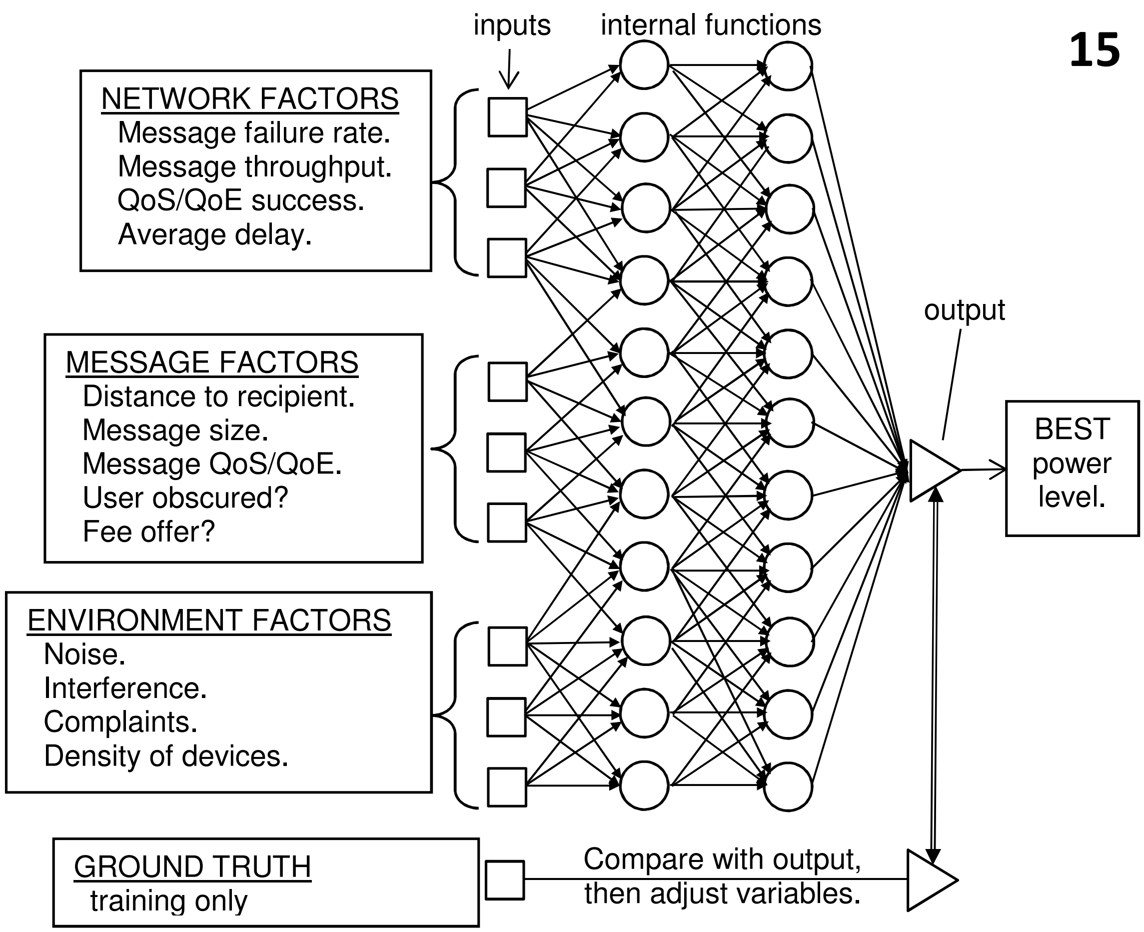

Fig. 15: An AI model exploits hidden correlations between the input parameters, and calculates either a most-likely prediction indicated by those correlations, or in this case, the optimal transmission power level.

Figure 16 shows how a single node of the AI model works. Each internal function or node is a simple, self-contained calculator with adjustable variables. It takes in values from the model inputs or from the previous layer, and combines them algebraically using an offset-weighted sum as shown (only 3 inputs shown, usually many more). The X values are the function inputs, the O values are variable offset values, and the W values are variable weighting factors. That sum is then limited ("squashed") to the range of ±1, using a sigmoidal limiter function. The squashed results are then distributed to the next layer or to the final output of the model.

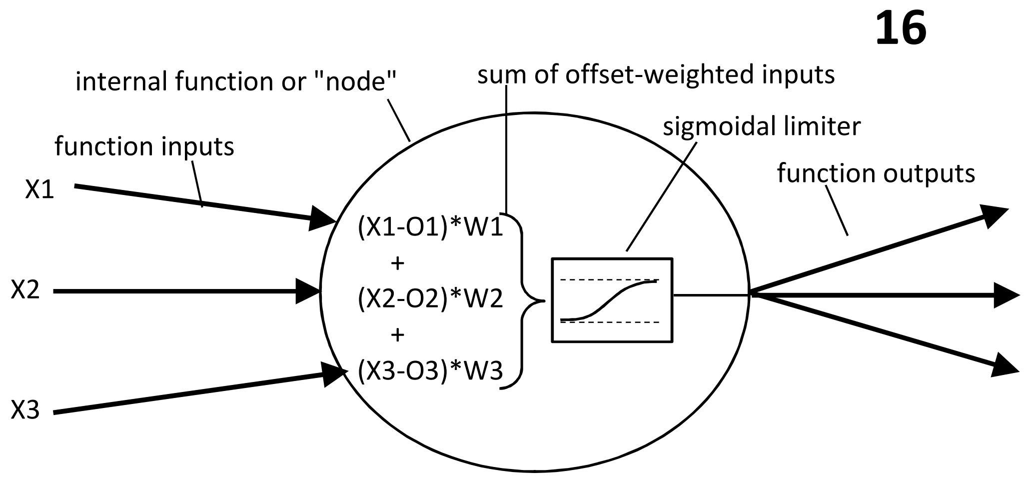

Fig. 16: Internal workings of an AI node.

Although the operation of one node is rather simple algebraically, when combined with many other nodes and many input factors, the AI model can often uncover subtle correlations that enable surprisingly good predictions. Sometimes the correlations are so complex, no human could ever understand them - but the computer easily uses them for predictions (easily, that is, after being trained on millions of examples).

Large AI models have billions of inputs, billions of layers, and billions of adjustable variables, and they rely on massive machine learning (as opposed to human intervention) to adjust those variables. After millions or billions of examples, such models can provide amazingly good predictions in whatever field is covered by the examples. For example, in network operations, AI can help improve the throughput, fault rate, latency, and energy consumption - all at negligible cost after training.

Regarding the deeper functionality of AI, the figure clearly shows that each node is just a simple calculator, and hence the AI model is basically a large multi-channel calculator. Despite the "artificial intelligence" name, it is not intelligent in any meaningful sense of the word. It is a computer algorithm or a gate array designed to detect correlations in the example data, and nothing more. Although AI models can become very good at finding intricate correlations, and then using them to make surprisingly accurate predictions, it has no "will" or agenda. Like any other inanimate tool, it can be used for good or evil, depending on how it is implemented by a human operator. If it does evil, blame the human operator, not the computer.

Value-Chain Analysis: AI-Based Beam Control

For users:

Optimal downlink beam control benefits users by providing improved signal quality and connection reliability, especially in adverse conditions. Only AI can provide the quick real-time compensation and adjustments needed to avoid perceptible interruptions in a crowded environment, such as a stadium.

Optimal uplink beam control is a major benefit to users, by minimizing transmission power usage while ensuring sufficient reception of uplink messages to avoid costly retransmissions.

For networks:

Since transmission power is a major energy cost for networks, anything that enhances both the downlink signal and its reliability will be of value to the network. AI can do exactly that by enabling narrower, more energy-efficient downlink beams, continually focused on the intended user. The same AI can also fine-tune the base station's reception beams to prevent uplink message faults, and the inevitable re-transmissions of current procedures.

After proper training, the AI-based beam control can provide real-time beam control at essentially zero cost. It will probably not be necessary for each network to develop its own AI model, since the problems are generally universal. A more economical solution would be for one network (or other wireless entity) to develop a versatile beam control AI model, and then distribute it to client networks with little or no localized modification required.

CONCLUSION

Narrowly focused beams are the future of wireless communications. Keeping those beams pointed in the right directions will require improved methods for alignment and power control. The methods disclosed herein provide efficient and economical new procedures for beam alignment and angular localization of each user, and for optimal power adjustment based on backgrounds and other conditions. With a few pulses of tailored, angle-dependent transmission, the base station can provide alignment service to all the users in a network simultaneously. By tracking each mobile user within a prepared reception map, the base station can continually maintain each communication link and virtually eliminate dead zones. With advanced AI-based control, the network can manage beam alignment, transmission power, and resource allocation for optimal user satisfaction and economy, all while minimizing energy consumption.

Networks implementing these techniques can keep ahead of demand, especially in the crowded communication spaces anticipated in the coming years, and thereby avoid the problems experienced in previous generations of wireless. We encourage standards organization such as 3GPP to include these beam alignment and localization procedures in future releases, so that developers can provide the advantages of rapid, low-cost beamformed communication to all users.

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GLOSSARY

3GPP (Third Generation Partnership Project) is the primary wireless standards organization.
AI (Artificial Intelligence) is a computer-based calculation emphasizing correlations in input data.
CBF (cell-barred flag) indicates whether a base station is private or public.
CSI (channel state information) indicates the signal quality in uplink.
DM (demodulation reference) indicates the amplitude and phase of a reference signal.
ELE (elevation) is the height of the base station's antenna.
IoT (Internet of Things) refers to wirelessly-connected, autonomous, sensors and actuators.
LAT (latitude) is a geographical coordinate of the base station's antenna.
LON (longitude) is a geographical coordinate of the base station's antenna.
OFDM (orthogonal frequency-division multiplexing) is a highly modulated message signal.
PBCH (physical broadcast channel) is part of the SSB message.
PSS (primary synchronization signal) is part of the SSB message.
QPSK (Quad Phase-Shift Keying) is a two-bit phase-only modulation system with 4 phase states.
RACH (Random Access CHannel) represents one step of user access to a network.
SRS (sounding reference signal) indicates the signal quality in downlink.
SSB (Synchronization Signal Block) is a system information message broadcast by base stations.
SSS (secondary synchronization signal) is part of the SSB message.
SIB1 (System Information Block type 1) is another system information message.
A "node" is an internal function of an AI model containing adjustable variables.
A "short-form demodulation reference" is a short transmission indicating certain modulation levels.
A "phased alignment pulse" is a transmission that varies in phase with angle.
An "amplitude alignment pulse" is a transmission that varies in amplitude with angle.
"Angle data" is an indication of an angle toward a particular transmitter, relative to North.
"Reciprocity" means that the same angle optimizes both transmission and reception.
"Uniform test signals" are identical signals during which a receiver can align its reception beams.

REFERENCES

[1] Patents on beam alignment and localization can be found at www.UltraLogic6G.com.

US Patent/Publication	Title
12,143,189	Low-Complexity Procedure for 5G/6G Beam Alignment
12,095,550	Low-Complexity Beam Alignment by Directional Phase in 5G and 6G
11,398,850	Rapid Doppler Correction for Mobile V2X Communication in 5G/6G
11,411,612	Location-Based Beamforming for Rapid 5G and 6G Directional Messaging
11,424,787	AI-Based Power Allocation for Efficient 5G/6G Communications
11,438,033	Location-Based Power for High Reliability and Low Latency in 5G/6G
11,509,381	Resource-Efficient Beam Selection in 5G and 6G
11,533,084	Automatic Adjustment of Transmission Power for 5G/6G Messaging
11,581,919	Transmission Power Compensation by Attenuation Mapping in 5G and 6G
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11,782,119	Phased Beam-Alignment Pulse for Rapid Localization in 5G and 6G
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2023/0179261	Automatic Condition-Based Adjustment of Transmission Power in 5G and 6G
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2024/0045013	Deterministic Low-Complexity Beam Alignment for 5G and 6G Users