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BPS for National Security

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Abstract—GPS (Global Positioning System) is a vital location and positioning service for economic and national security, widely used by the general population and in various sectors, such as precision agriculture; however, it has accidental or intentional vulnerabilities. BPS (Broadcast Positioning System) uses the infrastructure of the second generation of the Digital Terrestrial Television System ATSC 3.0, has little impact on system capacity, and has the potential to be a backup to GPS for national security purposes. This study simulates BPS coverage in densely urbanized and rural areas, where the main application is precision agriculture. The field strength for BPS coverage considered the requirements of the TOA (Time of Arrival) concept and the transmission and reception parameters with distinct losses for indoor urban, outdoor urban, and rural environments. The study presents an overview of the potential coverage of BPS.

Index Terms—GPS, BPS, ATSC 3.0, PLP, Coverage analysis, Field strength, Indoor reception, Outdoor reception.

I. INTRODUCTION

LOCATION and positioning services are vital to economic and national security and have generated a demand for high-performance systems such as GPS (Global Positioning System). GPS is an ultra-reliable service, available free of charge, with no subscription fees for the end user. These attributes have encouraged the widespread adoption of GPS, incorporated into more than 7 billion devices, including cars, boats, airplanes, smartphones, watches, and much more [1].

GPS uses the concept of TOA (Time of Arrival) to calculate the distance between a satellite and a receiver. The satellite continuously sends time messages, and receivers use this information to calculate how long it takes for the signal to arrive. By subtracting the time sent by the satellite from the receiver's time, the system delay time is obtained. By multiplying the system delay by the wave propagation speed, the distance between the satellite and the receiver is obtained. If the receiver identifies the distance of 1 satellite, it can only determine one radius of possible position. If the receiver identifies the distance of 2 satellites, it can determine 2 intersections of 2 radius, that is, 2 possible positions. If the receiver identifies the distance of 3 satellites, only one position will have 3 intersections; therefore, GPS needs at least 3 satellites to determine the receiver's position [2]. Since the satellites are in motion, it is necessary to estimate the speed to perform the Doppler Effect estimation. To increase robustness, 4 satellites are generally used to provide greater system robustness. GPS produces accuracy in the range of 30 to 100 meters [3].

GPS reliability is very high, but it has vulnerabilities because it orbits the Earth tens of thousands of kilometers above

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the ground, operates at low power, and transmits on known frequencies. GPS can be temporarily or permanently disabled by natural causes, such as solar flares, or by intentional causes, such as GPS jammers, and from a military perspective with weapons capable of destroying satellites [1].

BPS (Broadcast Positioning System) is a location and positioning technology that uses the infrastructure of the second generation of ATSC 3.0 digital television, transmitted by television stations, being ideal as a backup to GPS and with an important national security function.

This study shows a simulation of BPS coverage, considering the effectiveness of the service in densely urbanized areas and in rural areas for precision agriculture.

II. BPS

BPS is a location and positioning service that uses the ATSC 3.0 transmission system. The second generation of digital television in Brazil, known as TV 3.0 or DTV+ adopted the physical layer of the ATSC 3.0 standard, therefore it is compatible with BPS [4]. BPS was developed to provide location and positioning if GPS is unavailable. BPS uses the same TOA concept used in GPS, but the time messages are sent by terrestrial television stations. Receivers use the time information to calculate how long it takes for the signal to arrive, in order to obtain the distance between the terrestrial television station and the receiver. Like GPS, BPS needs at least 3 terrestrial television stations to determine the receiver's position [5]

ATSC 3.0 has the PLP (Physical Layer Pipes) concept, which are logical channels that carry one or more services with particular robustness. They can be used for audio and video or other services, such as BPS. It allows up to 64 PLPs, and at the receiver, it is possible to simultaneously decode up to 4 PLPs from the same frame. Each PLP can be configured with a different MODCOD (modulation and coding) and a different number of OFDM symbols [6]. Fig. 1 illustrates the PLP concept.

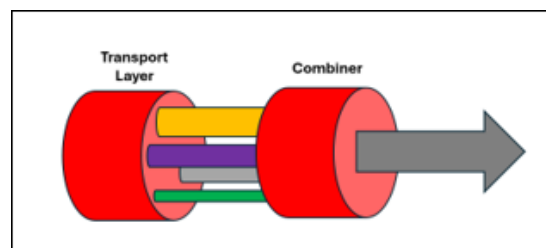


Fig. 1. PLP concept.

The BPS does not require a high bitrate, therefore it can use a small number of OFDM symbols and the most robust

MODCOD configuration. Table II shows the possible PLP configuration intended for the BPS, with low impact on the total system capacity.

Possible PLP configuration intended for the BPS.

Parameter	Value
PLP ID	16
Size	8100 Bytes
FFT Size	8K
OFDM Symbols	35
Modulation	QPSK
FEC	LDPC 2/15
PLP Bitrate	8 kbps
Minimum C/N	-5.55 dB

BPS coverage can be analyzed by coverage simulation. To assess the impact of the field strength thresholds proposed in this study, we conducted simulations using the Progira© software [7], which operates on the ArcGIS platform [8]. The software was configured to show BPS coverage if it receives the E_{med} (Minimum Median Equivalent Field Strength) from equations (1), (2) and (3), at least 3 different stations, where E_{min} is the equivalent minimum field strength calculations P_n is the receiver noise input power, A_α is the effective antenna aperture of the half dipole, L_f is feeder loss, C/N is the requirements dictated by the selected MODCOD, L_{BEL} is the loss through building structures, G_{Rx} is the receiver antenna gain, P_{mmn} is the allowance for man-made noise, L_h is the height loss for reception points at 1.5 m above ground level, C_l is the location correction factor, σ_m^2 is the macro-scale variance, σ_{BEL}^2 is the building entry loss variance and is a distribution factor to account for the variability of the electric field according to the percentage of receiving locations where the electric field strength level will be higher than its median value [9].

$$E_{min} = C/N + P_n - G_{rx} - A_\alpha + L_f + 145.8. \quad (1)$$

$$E_{med} = E_{min} + P_{mmn} + L_h + L_{BEL} + C_l(\sigma_m, \sigma_{BEL}). \quad (2)$$

$$C_l = \mu \sqrt{\sigma_{BEL}^2 + \sigma_m^2}. \quad (3)$$

In GPS, the satellites in motion result in a precision error due to the Doppler Effect estimation. In terrestrial television stations are not in motion, however, in the terrestrial transmission channels, there may be a precision error of multipath and clock offset. Multipath can cause large delay spreads, due to the combination of direct, reflected, refracted and diffracted waves, and Doppler Effect. The timing information transmitted on the preamble of the ATSC 3.0 can cause the clock offset of the order of the distance of the tower and the receiver. Position accuracy of the BPS can achieve a mean error of 35 m with a standard deviation of 22 m and clock offset estimation error had a mean of -50.6 m, with a standard deviation of 25 m, due to the unresolved multipath [10].

In any ranging system, the receiver and transmitter geometry influences position precision. If the transmitters are far apart, a relatively small region in which the receiver must lie with some degree of certainty. If the transmitters are closer, the position uncertainty is considerably larger, causing high GDOP (Geometric Dilution Of Precision) [11].

III. BPS IN A DENSE URBAN AREA

We selected the São Paulo metropolitan area, the most populous in Brazil, for coverage simulations. Currently, there is no approved second-generation digital television coverage project, so it is estimated that each broadcaster should install its own HPHT structure around Downtown, and broadcasters wishing to install complementary LPLT stations to cover shadow areas will possibly use shared structures in outlying regions. A conservative analysis considers 3 HPHT stations around downtown and 10 LPLT stations in peripheral regions in the new frequency range of 250 to 322 MHz. The HPHT considers a transmission power of 25 kW and an omnidirectional antenna array with 12.4 dBd gain, and the LPLT considers a transmission power of 250 W and an omnidirectional antenna array with 10.6 dBd gain.

The coverage prediction considers equations 1, 2 and 3. In densely urbanized areas, location and positioning are mainly performed by smartphones. In the worst-case scenario, smartphones are 1.5 meters from the ground, have antennas of limited size, with MIMO and around -4.7 dBd, and may be in either an indoor or outdoor reception. For indoor environments, an antenna reduction loss of 14.5 dB and a penetration loss of 14 dB were considered [12], resulting in an E_{med} of 59.98 dBV/m. For outdoor environments, an antenna reduction loss of 14.5 dB and a penetration loss of 0 dB were considered [12], resulting in an E_{med} of 45.98 dBV/m. Fig. 2 shows BPS coverage in indoor and outdoor configurations.

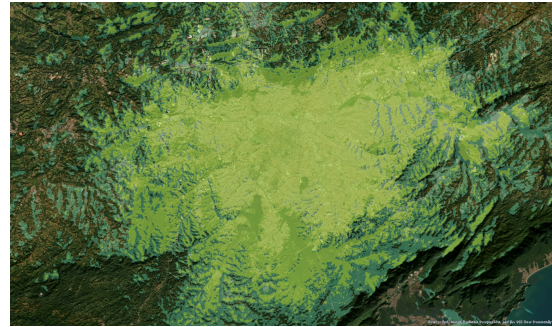


Fig. 2. BPS coverage in São Paulo with 3 HPHT and 10 LPLT station and 10 LPLT. Outdoor urban area in blue and indoor urban area in yellow.

In outdoor environments, coverage reaches almost the entire urban area, attending the main application for urban areas. Indoor environments showed a lack of coverage in some points of the urban area. A smartphone that travels in areas without indoor antenna coverage tends to have intermittent BPS service, like what happens with GPS when traveling through obstructions, such as tunnels.

The 3 HPHT are the most important for increasing BPS coverage; however, they are located very closer, which can lead to high GDOP. The 10 LPLT are less critical for increasing BPS coverage, but they contribute significantly to spacing the transmitters further apart, thereby reducing GDOP.

IV. BPS IN THE INTERIOR CITY

We selected Não-Me-Toque because it is considered the National Capital of Precision Agriculture, meaning it has a high demand for location and positioning in rural areas. Currently, there is no approved project for second-generation digital television coverage, so it is estimated that the interior will only have shared LPLT stations. A conservative analysis considers that first-generation digital television stations within a 80 km radius of the center of Não-Me-Toque will have second-generation digital television stations, resulting in 25 LPLT stations around Não-Me-Toque in the new frequency range of 250 to 322 MHz. The LPLT considers a transmission power of 250 W and an omnidirectional antenna array with 10.6 dBd gain.

The coverage prediction considers equations 1, 2 and 3. In urban areas, the location and positioning is similar to that calculated in densely urbanized environments, with an E_{med} of 59.98 dBV/m for indoor environments and an E_{med} of 45.98 dBV/m for outdoor environments. In rural areas, the main application is precision agriculture, where it is necessary to maintain an antenna reduction loss of 12 dB without loss of penetration, and since it is a professional activity, a higher gain antenna, on the order of 10 dBd, is viable, resulting in an E_{med} of 31.28 dBV/m. Fig. 3 shows the BPS coverage in urban indoor, urban outdoor, and rural configurations.

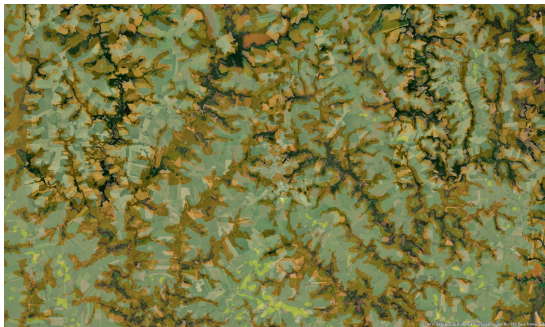


Fig. 3. BPS coverage in Não-Me-Toque with 25 LPLT. Outdoor urban area in blue, indoor urban area in yellow and rural area in orange.

In the urban environment of the inland city of Não-Me-Toque, the BPS does not have adequate coverage for location and positioning, as the service may be intermittent even in outdoor environments. In rural environments, in a professional activity with higher gain antenna, coverage is almost entirely reached, suitable for precision agriculture.

The 25 LPLT studied are regularly spaced across inland cities, thus presenting an ideal situation for lower GPDO.

V. FUTURE WORK

In this study, we have focused our analysis on BPS coverage area in a dense urban area and rural area. As important as

analyzing the BPS coverage area is verifying the accuracy of the position precision. Although studies indicate good BPS accuracy on typical television stations, future research should investigate the GPDO under the same conditions presented in this paper.

VI. CONCLUSION

BPS is a location service that uses the second-generation ATSC 3.0 digital television infrastructure, with little impact on system capacity and with the potential to be a backup for GPS for national security purposes.

By simulating the coverage area of the PLP responsible for the BPS service, it was possible to calculate a minimum intensity of 59.98 dBV/m for an urban environment with an indoor antenna, 45.98 dBV/m for an urban environment with an outdoor antenna, and 31.28 dBV/m for precision agriculture applications in rural environments.

The coverage area obtained shows good BPS service in dense urban environments, although there may be small areas with intermittent service, like what happens with GPS when it travels through obstructions, such as tunnels. In rural areas, where the main application is precision agriculture, the coverage area shows good BPS service with professional, higher-gain receiving antennas.

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