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ADAPTIVE VIDEO TRANSMISSION OVER HYBRID MIMO SYSTEMS BASED ON THE PARAFAC MODEL

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ABSTRACT

A hybrid MIMO scheme for video transmission based on the PARAFAC model is presented. This hybrid scheme is built by modelling the received signal as a 3D array, or tensor, and the tensor decomposition known as PARAFAC is used for the recovery of the information in the receiver and the channel estimation. Additionally, two algorithms for video transmission that make use of the presented scheme are developed. The proposed algorithms were built based on the H.264/AVC and H.265/HEVC standards.

Keywords: MIMO, PARAFAC, Tensor, H.264/AVC, H.264/AVC.

INTRODUCTION

In recent years, the popularity of smartphones has led to a change in the way users consume multimedia services over the internet. Users demand high quality of service while playing real-time video footage in moving conditions, while traveling on public transport, for example, or while holding video conferencing on their mobile devices. The massification of this type of services represents a great technical challenge for the wireless communications systems.

The development of the infrastructure that supports and offers these services represents a great technical challenge. The inclusion of multiple antennas on both sides of the link in a wireless communications system known as MIMO (Multiple-Input Multiple-Output) is one of the key technologies that have been proposed in communications standards as a solution to improve transmission. Also, the signal processing is a fundamental solution in the development of transmission systems. Multiple proposals are presented in the academic literature and the research is intense.

One of the technical problems in the transmission of information is the knowledge of the communications channel in the receiver, which is necessary for the retrieval of the transmitted information. Channel identification usually uses training sequences. The transmitter sends these training sequences periodically and from which the receiver has complete knowledge. However, the transmission of these sequences inevitably affects the rate of transmission. For this and other reasons it has been developed processing techniques known as blind detection, which is based on the identification of the channel without any prior knowledge. In this work, we present a hybrid MIMO communications system for which we developed a signal processing technique based on the parallel tensor mathematical model known as parallel factor analysis (PARAFAC), as a method for Blind channel detection.

On the other hand, in the field of video processing, compression techniques have been developed to help to eliminate redundant information in order to reduce its size. Among those compression formats are the AVC/H.264, developed in 2003, and the HEVC/H.265, developed in 2013. Developing algorithms for the transmission of high quality video is also an important technical challenge and a latent need. In this work, we propose two algorithms for the transmission of video coded in AVC and HEVC.

METHODOLOGY

PARAFAC decomposition

The PARAFAC decomposition is a tensor decomposition method, also known as factor analysis, which characterizes a tensor as a linear combination of external product factors. The decomposition PARAFAC can be seen as a generalization of the decomposition of singular values, SVD. A tensor can be presented intuitively as a multidimensional array, in the same way that a matrix is a two-dimensional array.

The decomposition PARAFAC factorizes a tensor in a sum of tensors component of rank one. Thus, if we consider a tensor of third order (I x J x K) denoted by singular elements, then its tensor decomposition is given by

$$x_{i,j,k} = \sum_{r=1}^{R} a_{i,r}\, b_{j,r} c_{k,r}$$

Where x = 1, …, I; j = 1, …, J; k = 1, …, K.

The PARAFAC decomposition can also be decomposed metrically in the following manner:

$$X_i = BD_i(A)C^T$$

Where, $\boldsymbol{B}$ and are factor matrices with elements $[A]_{i,r} = a_{i,r}$, $[B]_{j,r} = b_{j,r}$, $[C]_{k,r} = c_{k,r}$. The operator $D_i(A)$ forms a diagonal matrix with the i-th row of its diagonal.

The complete tensor can be represented by concatenating each slice, represented by the above equation, as follows:

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$$\acute{X} = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_I \end{bmatrix} = \begin{bmatrix} BD_1(A) \\ BD_2(A) \\ \vdots \\ BD_I(A) \end{bmatrix} C^T = (A \lozenge B)C^T$$

Where ◊ Denotes the Khatri-Rao operation.

One of the benefits offered by PARAFAC decomposition is uniqueness, which means that under certain conditions, which will be presented at once, the decomposition is unique. The concept of oneness is closely related to that of rank k.

The range k of A, denoted byK_A, s equal to r, and only contains a set of linearly independent r columns, but no set of r + 1 linearly independent columns.

One of the best known uniqueness tests of PARAFAC is the one presented by Kruskal [18], which states that a sufficient condition for the uniqueness of PARAFAC decomposition is

$$K_A + K_B + K_C \geq 2R + 2$$

Video encoding

At present, conceiving internet without video services is unimaginable. Years ago, thinking about real-time video transmission over the internet was technologically very complex, and if that transmission was possible, it was not very reliable. Currently, the computational capacity of the equipment has increased significantly. This has contributed to the development of

More efficient video compression and thereby improve video services through wireless communications systems.

In the last years, many different techniques have been proposed and investigated on video codification. Hundreds of investigative articles have been published each year describing innovative new compression techniques. In contrast to this wide variety of innovations, commercial video encoding applications tend to employ a limited number of standardized techniques for video compression. Standardized video compression formats have a number of potential benefits compared to non-standard ones:

- Standards simplify interoperability between encoders and decoders from different manufacturers.
- Standards make it possible for platforms to incorporate videos, in a large number of applications such as video encoders, audio encoders, transport protocols, security and copyright management.

In this way, it is clear that the Advanced Video Coding (AVC) and High Efficiency Video Coding (HEVC) standards are fundamental part of the way in which we conceive today the exchange of videos over the internet. The new version of Hyper Text Markup Language (HTML5) supports the <video></ video> tag. This allows the insertion of video within web pages easily and dynamically; In addition, this tag supports two formats of compression: one of them AVC, and in the years to come it will support HEVC. This interoperability makes building applications and cross-platform content easier. Similarly, this change forces compression standards to evolve constantly. An example is the VP8 standard developed by Google as an AVC counterpart.

H.264 / AVC is a video coding standard developed by the International Telecommunication Union (ITU-T) and the International Organization for Standardization / International Electro technical Commission (ISO / IEC) which defines the format or syntax of compressed video and decoding method. This standard defines a general coding scheme but not an explicit way of doing so; the co-developer's implementation is the responsibility of the developer or manufacturer. It should be clarified that the encoded video must comply with the syntax established by the standard so that the decoder can later recognize the input bit string as a valid H.264 video sequence.

When a video is encoded in H.264 / AVC the result is a string of compressed video bits. In order for the decoder to be able to reconstruct the original video, it is necessary that the bit string have an orderly structure that allows identifying what type of information is contained in each section of the string. This is why the standard provides a high-level syntax that allows you to characterize the bit string clearly. This syntax separates the bit string into Network Abstraction Layer (NAL) units. In H.264, it is possible to have 32 types of these units some are Video Coding Layer (VCL).

The H.265 / HEVC video coding standard is the joint project of the ITU-T Video Coding Experts Group (VCEG) and ISO / IEC Moving Picture Experts Group (MPEG), working together to form the Joint Collaborative Team on Video Coding JCT-VC). HEVC has been designed to meet all existing AVC standard applications and particularly focus on two major issues: increasing video resolution and increasing the use of parallel architectures for processing. As has been the case with all ITU-T video coding standards andISO / IEC, in HEVC only the bit string and its syntax are standardized. The first version of the standard was published in 2013 and the current version was published in April 2015.

The high-level syntax employed by HEVC contains numerous AVC elements. NAL units provide the ability to map data from the video encoding layer to various types of packaging in the transport layer, including RTP, ISO MP4, etc. This syntax provides an error-resistant tool. The units

NAL are classified in VCL and non-VCL depending on what type of information the unit contains.

System modeling

An efficient way to capitalize on the MIMO channel is the use of spatial multiplexing, which aims to provide high transmission rates without sacrificing bandwidth, since their operation is based on the transmission of different samples of the signal simultaneously. Another approach used to exploit the MIMO channel is the use of the method known as spatial

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diversity, which seeks to improve the reliability of the transmitted information by sending redundant samples of the transmitted signal. A hybrid MIMO system combines these two approaches.

The communication system employed is that presented in [20]. It is considered a system of T transmitting and receiving antennas. The transmitting antennas are divided into K transmit groups, each of which employs $L_k$antenna, with k = 1, 2, …, Kand T = $L_1 + \cdots + L_K$.

Each group of transmitting antennas has its own transmission scheme, which means that each block can have different diversity gains or multiplexing. For this scheme, the degree of diversity or multiplexing of each Transmitter block is defined by one of the matrices of the PARAFAC model, which will be presented shortly. The degree of redundancy or diversity is defined by P, that is, each symbol is repeated for P consecutive symbol periods.

The matrix, which is associated with the k-th transmitter block, is defined. This matrix defines the way in which the symbols are transmitted through the dimensions of space and time. The degree of diversity and multiplexing can be controlled by properly choosing the coefficients of this matrix. The matrix represents the MIMO channel between the transmitting antennas of the k-th group and the R receiving antennas. And finally, it is the symbol matrix of the k-th transmitter block in the n-th symbol period.

The p-th redundancy symbol of the received signal in the n-th symbol period on the r-th receiving antenna can be expressed in scalar form as

$$x_{i,j,k} = \sum_{k=1}^{k} \sum_{L_k=1}^{L_k} s_{n,l_k}^{(k)} w_{p,l_k}^{(k)} h_{r,l_k}^{(k)} + v_{n,p,r}$$

Which can be interpreted as the (n, p, r)-th element of a third order tensor $\acute{X}(N \times P \times R)$, which, according to the definition PARAFAC, can be decomposed as a sum of K tensors. The term V is the additive noise.

The received signal can also be written in matrix form as

$$X_n = \sum_{k=1}^{K} W_k D_n(S_k) H_k^T + V_n$$

Where (P X K) is, the matrix of the received signal in the n-th symbol period, y is an operator that forms a diagonal matrix with the n-th row of its matrix argument on its diagonal.

The set of matrices are estimated through the algorithm of alternating least squares. This algorithm adjusts all matrices, except for the matrix in question, which makes it possible to convert a natural optimization problem into several independent least squares linear problems.

Each iteration consists of three least-squares estimation steps. In the first step, a matrix, for example, is obtained from the remaining (y), which are adjusted to the values obtained in the previous estimation steps.

Given the received signal, the channel estimation and the recovery of the symbols is done through this algorithm.

Proposed transmission algorithms

The Cross-Layer optimization allows us to adapt the different layers of the communication system depending on the type of service to be provided and its conditions. To this extent, the idea is to make the video transmission system, coupled in such a way as to improve the performance of the entire system and to treat the video bit string in such a way as to prioritize the most important sections and to increase the transmission speed in sections where possible.

AVC and HEVC video encoders organize the video bitstream in NAL units. Depending on the encoder the quantity of these units changes, but within that variety of NAL units there are some that are more valuable than others at the time of rebuilding the video, because of that, it is convenient that the system adapts to the moment of transmitting that information, and that allows to shield the most valuable units and improve the transmission rate with those that are not.

The traditional layered approach in networks tends to not fit very well in wireless communications systems, due to the number of users accessing a scarce and random transmission medium. The performance of some systems can be optimized by considering some coupling between the layers. This interaction between the layers provides useful information allowing an improvement in network performance. Cross-layer optimization defines a general concept of inter-layer communication, considering certain intelligent interactions between them, resulting in improved network performance. In Figure-1, we can see the possible interactions that may exist between layers.

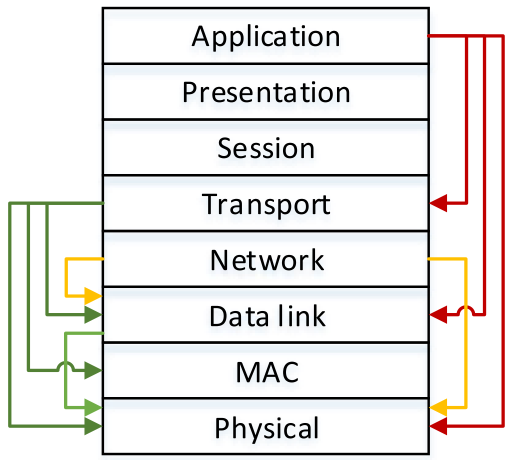

Figure-1. Possible interaction between layers.

The traditional closed layer model does not follow the unstable conditions of the dynamic nodes of wireless networks as best as possible, making obvious the

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need for a flexible approach. Vertical communications provide a shortcut in the delivery of relevant information resulting in a configuration in each of the particular layers. The key to Cross-Layer optimization is to find an appropriate way to abstract each layer and appropriate mating mechanisms.

Next, the proposed algorithms for adaptive video transmission for video formats compressed with AVC and HEVC are presented. The algorithms are coupled for operation with the PARAFAC transmission system presented in this work. The proposed algorithms are based on the knowledge by the transmitter of the type of information to be transmitted, so depending on the type of video is structured a transmission scheme that provides the best conditions at the time of sending the packages. From This way it is possible to achieve a more transparent and better performance interaction between the different layers that make up the system and therefore provide a better performance.

In Figure-2, it is possible to observe the proposed algorithm for AVC video transmission, and then explained in detail

- As a first step a video in YUV format is encoded in an AVC bit string. For this, an encoder made by the Fraunhofer Institute was used, which allows a detailed configuration of the way in which the video will be encoded. This encoder allows you to choose the sequence type of the frames and how they will be encoded.

- As explained above, this bit string is divided into NAL units. In order to guarantee that the video can be decoded, the NAL units of the beginning of the string, in addition to the first IDR frame, are guaranteed for checking the algorithm. Therefore, the algorithm would only have effect on the units containing the frames.

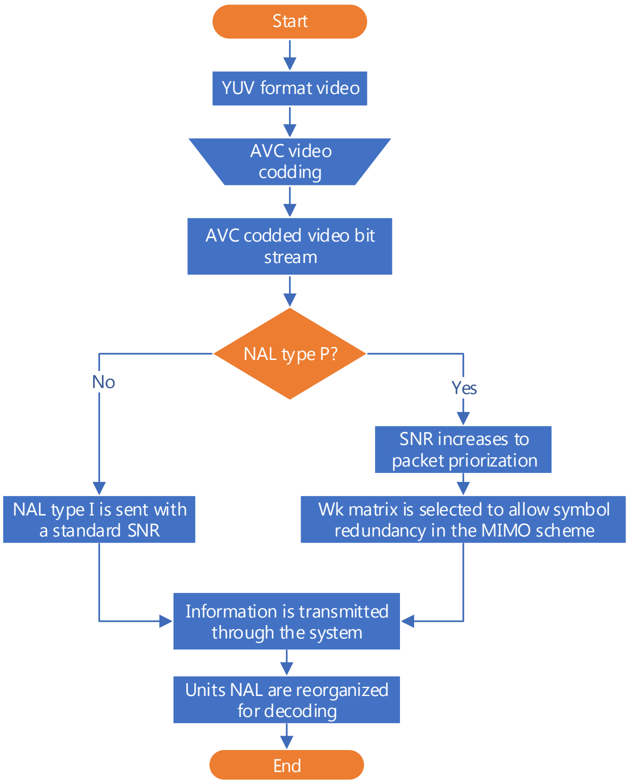

Figure-2. AVC adaptive video transmission algorithm diagram.

- Once the NAL units are identified, the ones with type I and type P frames are separated. To do this, the program performs the bit string of the video and interprets the header of each of the NAL units; Later identifies which type of box is encapsulated and stores these addresses for further processing.

- If the unit contains a P-frame, the algorithm indicates that the signal-to-noise ratio of the transmission must be increased and that a matrix Wk must be chosen to apply redundancy to the symbols and ensure optimum transmission.

- In this specific case it is somewhat confusing to give a higher priority to type P frames and not to type I frames that contain more information, but it was observed through the simulations that the AVC decoder better tolerates losses in The type I units that type P and therefore the algorithm tries to shield this type of packages.

- In the case of type I frames, a standard transmission is performed, which guarantees a higher transmission speed and improves the latency periods. As mentioned in the previous point it sounds a bit contradictory to give priority to packets containing P-type frames, but this is because the coding of type I frames is spatial,

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while type P uses temporal coding. Because of this, the losses of type P frames affect visually more than losses of type I frames.

- In the receiver after the decoding of all stages of the communication system reorganizes the NAL units to be delivered to the AVC decoder, which subsequently delivers the reconstructed video.

- In Figure-3, it is possible to observe the proposed transmission algorithm, and then explained in detail.

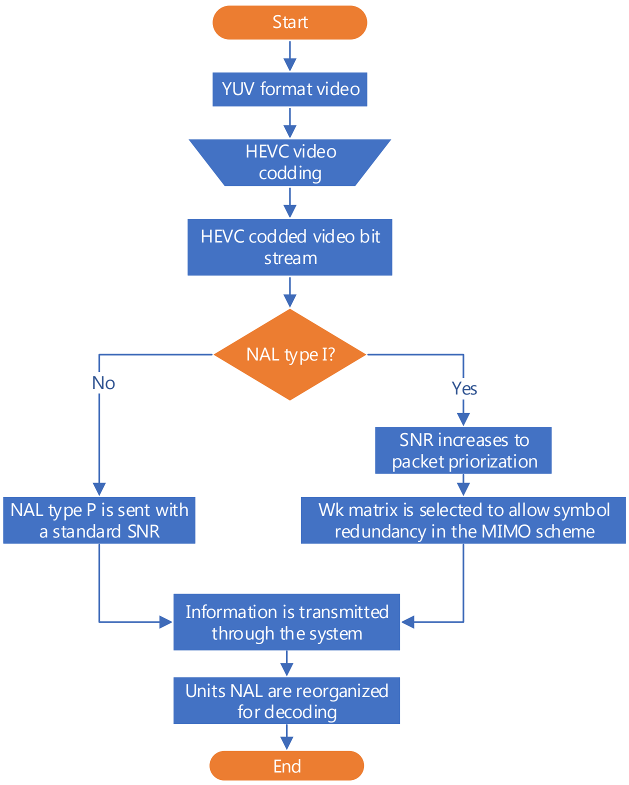

Figure-3. Diagram of adaptive video transmission algorithm HEVC.

- As a first step a.yuv format video is encoded in a HEVC bit string. For this, an encoder made by the Fraunhofer Institute was used, which allows a detailed configuration of the way in which the video will be encoded. This encoder allows you to choose the sequence type of the frames and how they will be encoded.

- As previously explained, this bit string is divided into NAL units. In order to guarantee that the video can be decoded, the NAL units of the beginning of the string, in addition to the first IDR frame, are guaranteed for the purpose of checking the algorithm. Therefore the algorithm will only have effect on the units containing the frames.

- Once the NAL units are identified, the ones with type I and type P frames are separated. To do this, the program performs the bit string of the video and interprets the header of each of the NAL units; Later identifies which type of box is encapsulated and stores these addresses for further processing.

- If the unit contains a type I frame, the algorithm indicates that the signal to noise ratio of the transmission *must be increased and that a matrix Wk, must be chosen so* as to apply redundancy to the symbols and to ensure optimum transmission. In this case, the opposite occurs with respect to the AVC video transmission algorithm. By means of the simulations it can be seen that the HEVC video decoder recovers better to the losses of the type P packets than the type I packets, this because the compression is greater since the type I boxes store more compressed information than the Units containing the type P frames and therefore a small loss in units containing type I frames translates into a great loss of quality.

- In the case of P-type frames, a standard transmission is performed, which increases the transmission speed and improves the latency periods. In this case, the HEVC decoder best recovers the NAL units that contain P-type frames corrupted by the transmission, because in HEVC the interdependence between type I and type P frames is stronger and the predictions made by the type frames P on type I are more accurate and a loss in those units leads to more errors in decoding.

- In the receiver after the decoding of all stages of the communication system reorganizes the NAL units to be delivered to the HEVC decoder and later it can rebuild the video.

RESULTS

The simulations were performed in a communication system configured with 64QAM and OFDM modulation. Also, a turbo encoder was configured for transmission. The communications channel considered is a Rayleigh multipath propagation channel and additive white Gaussian noise. The system input consisted of a binary sequence of 2^{20} random bits.

As stated above, the $W_k$matrix defines the level of redundancy and the number of transmit antennas of each block. Many configurations are possible according to the elements that are defined in W_k .

The configuration defined for the MIMO schema consists of making $K = 2$, $L_1 = L_2 = 2$. The level of redundancy in $P = 2$. The W_k matrix are this:

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$$W_1 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}, W_2 = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$

Figure-4 shows the performance comparison of hybrid MIMO systems with PARAFAC model and hybrid MIMO without model PARAFAC. The receiver of the second system is perfectly aware of the communication channel, which leads to this system having the best performance, contrary to the PARAFAC system, which does not know the channel and carries out an estimation of this without any known parameters.

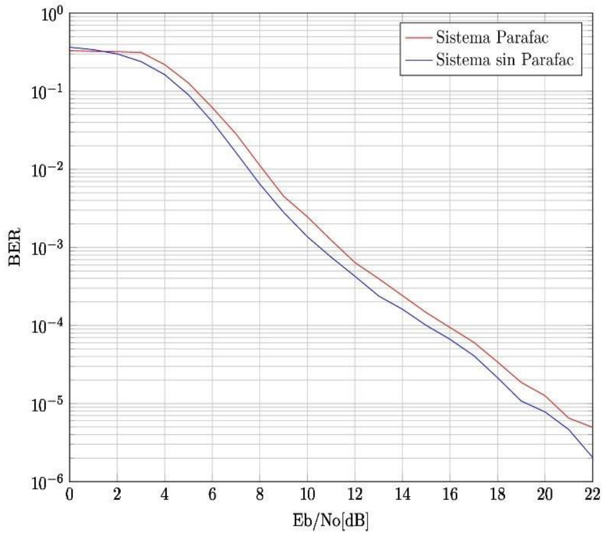

Figure-4. Performance of the system with PARAFAC model.

It should be noted that the initialization of the matrices strongly influences the speed of convergence of the algorithm of alternating least squares. The matrix is usually known at the receiver, which simplifies the steps of the algorithm of least squares alternating to single two. However, the PARAFAC model presented could estimate the matrices without the need to know a priori any parameter.

Thanks to the uniqueness of the PARAFAC tensor decomposition it is possible to estimate the transmitted channel and symbols without resorting to any previous knowledge about the system, such as sending from the receiver training sequences.

Digital video applications such as digital television, digital cinema, videoconferencing, IP television, mobile TV, real-time video transmission over the internet and wireless media always point to a human observer as an end customer. The evaluation of subjective video quality is generally used only as a percentage representation of the quality of the video, where it is intended to estimate the perception of the average observer.

Video evaluation subjectivity play a critical role in the design of video communications systems, from the point of acquisition of the video to its representation in front of the end user.

In Figure-5, three frames corresponding to the video sequence akiyocif.yuv can be observed. The first frame shows a frame of the original video coded with AVC, present in the transmitter of the system, the second frame corresponds to the result of the transmission of the original frame by means of the non-adaptive system and the third one is the result of the transmission of the frame with the proposed algorithm.

Figure-5. Results of video transmission akiyocif.yuvAVC.

It can be seen that the frame transmitted with the system using the adaptive algorithm, has a sharpness superior to the traditional system frame. This fragment of video corresponds to a sequence of movement at medium speed, in which a woman is observed presenting news. In the video there are few changes in the background, almost all changes between frames occur in the woman face.

In Figure-6, we can see three frames corresponding to the video carphone sequence qcif.yuv. The first frame shows a frame of the original video encoded with HEVC, present in the transmitter of the system, the second frame corresponds to the result of the transmission of the original frame through the non-adaptive system and the third one is the result of the transmission of the frame with the proposed algorithm. It can be seen that the frame transmitted with the system using the adaptive algorithm has sharpness higher than the traditional system frame. This video fragment corresponds to a medium-speed motion sequence. You see a man talking energetically. In the scene, the background remains almost static, while what changes mostly is the man's mouth while speaking.

Figure-6. Results of transmission of video carphoneqcif.yuv HEVC.

Figure-7 shows the result of the simulation of the video transmission adaptively using the PARAFAC system shown in this work. An improvement can be observed between adaptive and non-adaptive transmission. Handling the bit string in a special way makes the system much more adaptable and fault tolerant. In the case of the system that transmits AVC video it was decided to

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prioritize P-type packets because the video decoder responds better to small losses in packets type I than type P.

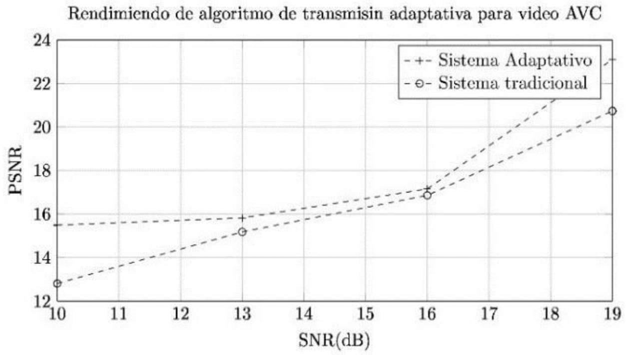

Figure-7. Results of the verification of the algorithm of adaptive transmission AVC.

The PSNR values with the proposed algorithm for AVC video transmission are relatively low because of the demanding simulation channel used. In general, performance is improved substantially. The algorithm makes the system transmit the video in a special way and that means that PSNR performance improves over non-adaptive transmission. In addition, using the PARAFAC model to perform channel estimation improves transmission times and low latency periods, which indicate that channel estimation procedures, should not be used during transmission. As long as you guarantee a good processing capacity, the total system performance is very good.

Figure-8 shows the result of the simulation of video transmission adaptively using the PARAFAC system shown in this work. An improvement can be observed between adaptive and non-adaptive transmission. Handling the bit string in a special way makes the system much more adaptable and fault tolerant. In the case of the system that transmits HEVC video it was decided to prioritize type I packets because the video decoder responds better to small losses in type P packets than type I.

The values of PSNR with the proposed algorithm for the transmission of HEVC video are relatively low due to the demanding that was the simulation channel used. In general, performance is improved substantially. The algorithm makes the system transmit the video in a special way and that means that PSNR performance improves over non-adaptive transmission. In addition, using the PARAFAC model to perform channel estimation improves transmission times and low latency periods, indicating that channel estimation procedures should not be used during transmission. As long as you guarantee a good processing capacity, the total system performance is very good.

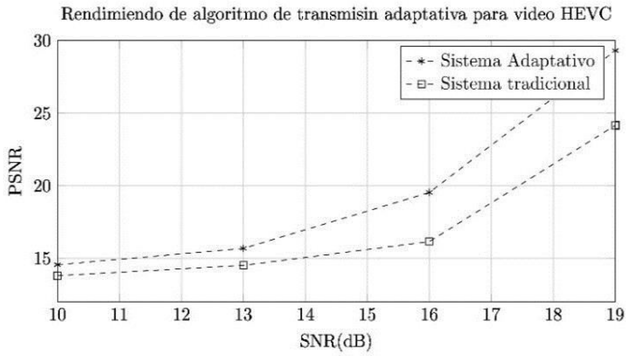

Figure-8. Results of the verification of the adaptive transmission algorithm HEVC.

CONCLUSIONS

In this paper, we have proposed a hybrid MIMO communications system based on the parallel factor analysis tensor model known as PARAFAC. Likewise, we have proposed two adaptive video transmission algorithms to improve the quality of the service in the presented communications system. One of the focuses of this paper is the modeling of the signal received in the receiver as a three-dimensional array. In general, we can conclude that the tensor modeling is useful in communications applications where the information signal has a multivariate nature, as analyzed in this paper, and, in general, in any field where this behavior occurs. Additionally, we can mention that multidimensional modeling in signal processing favors the creation of new approaches in the development of wireless communication systems in the sense that it allows the use of several forms of diversity, since the application of tensor decomposition techniques as the one analyzed here (PARAFAC) allows the separation of signals and the estimation of the channel, as in the communication system analyzed in this work. An intelligent wireless information transmission system helps to improve the quality of the service provided, since the knowledge of the type of information to be transmitted allows a configuration of the system in order to prioritize important packages. In the case of video, it is important to guarantee certain packages that, if lost, would be impossible to reconstruct or result in poor video quality. The algorithms proposed in this paper help to improve the quality of the service provided. These algorithms configure the transmission system in such a way that they shield the most sensitive packets according to the encoder used and increase the transmission speed with pieces of information that allow this.

In particular, we can highlight the following conclusions:

The performance of the communications system based on the tensor model is very similar to the system that does not use it. However, it should be clarified that the communication system based on PARAFAC presented in this paper introduces the advantage of that it requires to resort to any technique of knowledge of the channel, like training sequences, for the estimation of this one. It also allows the separation of signals from different combined

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sources in the receiver. This results as property of the tensor decomposition used.

The proposed adaptive video transmission algorithms show an improvement in the video quality received in the decoder. This is because the system adjusts to the nature of the information you want to send and therefore improves the transmission conditions.

When calculating the PARAFAC decomposition with the ALS algorithm, it is important to select the start parameters correctly; otherwise, the algorithm could take a long time to find convergence. There are libraries such as Tensor Lab 3.0 that allow you to find these parameters automatically.

Algorithms that focus on the retransmission of priority packets can improve the quality of the videos received. The scope of this work was to adapt the system to improve transmission, not to create recovery algorithms and priority management. This can be a good topic for future research work.

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