# Multipath Selection Mechanism for Wireless Video-Surveillance Systems

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***Abstract*—The main challenges for wireless video-surveillance systems are related to bandwidth availability and video transmission rates. Previous works indicate that partitioning the video using Multiple Description Coding (MDC) and transmitting each part through multiple paths can improve video streaming QoS. However, selecting the best set of paths is not a trivial task. Flows may interfere with each other during real-time transmission, especially in surveillance systems that require multiple sources. Thus, this paper presents a multipath selection mechanism called ILS-MDC, which is based on the Iterated Local Search (ILS) metaheuristic, for the selection of multiple paths for transmitting video descriptions between multiple sources and a sink. ILS-MDC uses the framework AFTER to minimize interflow interference and ILS to maximize the aggregate network throughput. Simulation results show the potential of ILS-MDC to increase wireless video-surveillance systems QoS.**

***Index Terms*—video-surveillance, multipath selection, multiple decription coding.**

## I. INTRODUCTION

Video-Surveillance Systems have been used in smart cities to support applications such as traffic monitoring and public security. Typically, the video transmission system consists of multiple video sources (cameras) and one or more monitoring centers. City cameras capture the real-time video and transmit it directly to the monitoring center over a wide-band transmission link [1].

The demand for a smart city video surveillance system along with the recent availability of inexpensive multimedia devices has promoted these systems. Wired networks have been used to connect devices in several cities. However, the high cost of deploying the wired networks impairs system scalability.

Wireless multimedia sensor networks (WMSNs) have emerged as a key technology to facilitate and reduce the cost of deploying these systems, as well as to provide mobility for multimedia devices [2]. However, performance is still not comparable with that of wired networks due to inter-flow interference in highly dense urban environments and self-interference between the nodes.

The performance of WMSNs depends on a routing protocol to determine stable and resource-efficient paths, and to guarantee adequate levels of QoS for multimedia [2]. Thus, one of the main challenges to support wireless video-surveillance systems is the implementation of highly flexible and adaptive routing protocols that may route multimedia traffic in an energy-efficient manner, while achieving the required QoS levels using low complexity encoders to alleviate the processing and transmission overheads for devices [3].

The design of routing protocols for WMSNs needs to be adapted according to the QoS requirements of multimedia applications, in terms of bandwidth, delay, and packet loss. Moreover, for video-surveillance systems that require transmission from multiple sources to a sink, finding suitable routes may be even more complex because that approach increases the probability of paths sharing nodes and links, thereby reducing the throughput. The throughput is compromised because, when multiple sources transmit simultaneously, the network load increases which may lead to congestion and collisions.

Multipath routing techniques for multiple sources can be adapted to address QoS requirements for wireless video-surveillance systems in order to increase network throughput. To this end, those routing techniques should be tightly integrated with multimedia source coding techniques, in a cross-layer approach involving the application layer and the network layer [4].

Multiple Description Coding (MDC) is a video coding technique that provides a solution to reduce the degradation of video quality in the presence packet losses, bit errors and burst errors during transmission [5]. The key idea of MDC is to partition the video stream into two or more independent descriptions. Thus, the descriptions can be transmitted through multiple paths to improve QoS.

Multipath transmission with MDC may increase throughput by dividing flows into different paths [6]. However, multipath routing protocols depend on the mechanism used for route discovery and for selecting a reliable path to meet certain objectives such as reducing congestion or fulfilling application's constraints (throughput, delay, and bandwidth).

Multipath selection in multi-hop wireless networks becomes more complex because the quality of a path is not determined only by the individual links qualities, but also by the complex patterns of self-interference between links [7]. Thus, evaluating which set of paths would result in the highest aggregate throughput can be challenging when one considers inter-flow interference.

In this paper, we present a multipath selection mechanism for MDC flows in order to maximize aggregate network throughput considering inter-flow interference between descriptions. This mechanism, called ILS-MDC, is based on the Iterated Local Search (ILS) metaheuristic [8]. Simulation results show significant improvements in aggregate network throughput compared to the methods used in related works and demonstrate the potential of the proposed mechanism to

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improve QoS.

The remainder of the paper is organized as follows. Section II presents a wireless video-surveillance system scenario and points out the characteristics of transmissions by multiple video sources with MDC. Section III presents the related work review. In Section IV, we present the ILS-MDC mechanism. The experimental setup and simulation results are discussed in Section V. Finally, conclusions and future work are provided in Section VI.

## II. WIRELESS VIDEO-SURVEILLANCE SYSTEM

Wireless video-surveillance systems are composed of interconnected cameras with video encoders connected over WMSNs. They are used to enhance public security and complement existing surveillance systems extending the ability of law enforcement agencies to monitor traffic, areas and public events [9].

There are different scenarios for wireless video-surveillance systems. In general, they require transmissions from multiple sources to a sink, such as monitoring centers that need to obtain video streams from multiple cameras distributed among the nodes of the WMSNs. A hypothetical scenario of an urban area with cameras deployed at each corner of a neighborhood of the city of Niterói is shown in Figure 1, where the blue video sources transfer video streams to a red monitoring center over multiple wireless hops. Those multiple sources can transfer flows simultaneously according to the demands of the monitoring center. For example, the monitoring center may enable some cameras to track an event or a target in a street or a block of the city region.

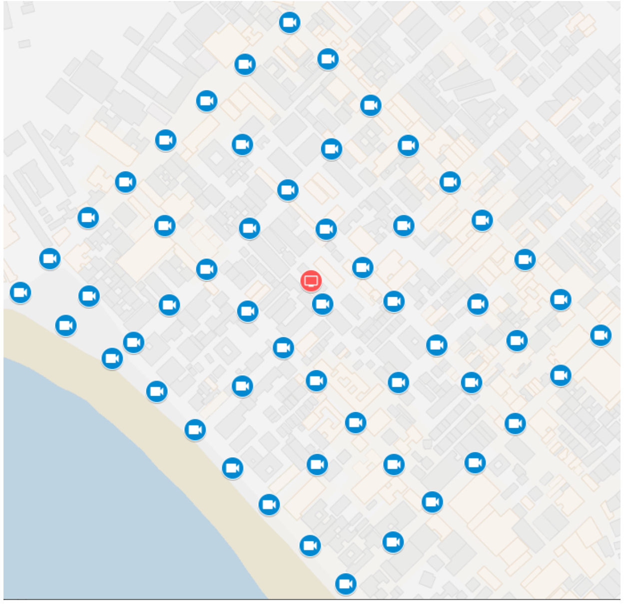

Fig. 1. Wireless video-surveillance system in urban area.

Multiple video sources may improve target tracking, suspicious activity identification, and automatic detection of eventual behaviors and have been used to monitor traffic, climate, safety and public events in smart cities [1] [10]. In this case, the number of active video sources depends on the requirements of the monitoring center. Usually, sources are enabled by segments of streets or blocks that require attention. However, the number of sources can influence QoS, especially if the multipath routing protocol ignores the aggregate network traffic requirements [1].

To provide better QoS using MDC with multiple paths, it is necessary to consider the aggregate network throughput to select better paths for each description according to the number of sources. The following section briefly addresses the usage of MDC associated with multipath selection.

### A. Multiple Description Coding

MDC is a video encoding/decoding technique that divides the video into independently-decodable and mutually-refinable descriptions [11]. Individual packets of each description can be transmitted separately, possibly through different network paths.

This technique provides better QoE (Quality of Experience) without the need to retransmit lost packets. Thus it is suitable for real-time video systems that do not accept excessive delays. When associated with multipath routing, MDC also enables traffic balancing and reduces network congestion [12]. Thus, selecting optimal paths for MDC flows through multipath routing can maximize the aggregate network throughput.

Multipath video transmission with MDC was adopted by [13] and [6]. Experimental results show that this method can improve performance in comparison to traditional video transmission systems that use a single path or do not adopt efficient multipath selection mechanisms.

Although it is possible to use other video coding techniques to transmit data through multiple paths, such as those based on the scalable video coding (SVC), multiview video coding (MVC) or existing high-efficiency video coding techniques (such as H.265/HEVC), the independence of MDC descriptions simplifies routing, and allows video with a certain quality to be displayed when at least one description arrives at the decoder.

There are several techniques to generate video descriptions using MDC. The number of descriptions is defined according to application requirements and the partitioning may be in the spatial or temporal domain. A review of the MDC partition technique is presented in [11]. Increasing the number of descriptions improves video quality, but if more paths are required, it can affect routing performance.

Because of the cross-layer interaction between the MDC at the application layer and the multipath routing protocol at the routing layer, the multipath selection mechanism needs to know the number of descriptions generated by MDC to define a set of paths. In this case, it is necessary to select $P$ distinct paths for the flows, with $P = \sum_{f=1}^{F} d_f$ where $F$ is the number of sources and $d_f$ the number of descriptions generated by the MDC encoder of the video $f$.

An example of transmission from multiple video sources to a sink using MDC through multiple paths is shown in Figure 2. For each of the $F$ sources, the MDC encoder

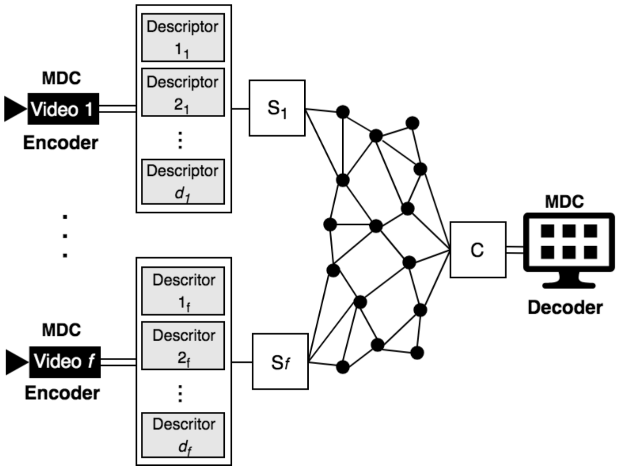

Fig. 2. MDC video transmission with multiple sources and multiple paths.

partitions the video into $d$ descriptions. These descriptions are transmitted from source nodes through multiple paths of a multi-hop network. At the sink node, the MDC decoder is responsible for synchronizing and merging the received descriptions for rendering the video. Since the descriptions are independent, acceptable video quality can be obtained if one of the description's packets is not affected by losses or delays.

To exploit this MDC multipath strategy, it is necessary to implement a multipath route selection mechanism associated with the MDC video coding that fulfills QoS requirements.

Traditional metrics to select optimal paths, such as shortest paths and hop count, are not necessarily the best options because they analyze links and paths individually and do not use a global view of network flows. In addition, they increase the probability that two or more paths share a link, which causes self-interference.

The disjoint path selection mechanism is adopted in several proposals and can provide better performance and reliability, but disjoint paths are rarely available for all descriptions sources [13]. Therefore, a more efficient multipath selection mechanism is needed to maximize the aggregated network throughput considering inter-flow interference.

## III. RELATED WORK

The main function of a multipath routing protocol is to define a selection mechanism to choose a set of viable paths between nodes. Multipath selection mechanism of a routing protocol for multimedia applications seeks to meet the QoS requirements, which are expressed as a combination of QoS parameters, according to each application [4]. Thus, different applications may have different QoS requirements.

Multipath selection mechanisms have been proposed in the literature to meet the demands on different QoS metrics such as delay, throughput, and reliability. These mechanisms are proposed to design routing strategies of a multipath routing protocol. In general, these strategies selecting a set of node/link disjoint paths or of partially disjoint paths, or braided multipath, according to with link individual quality, but do not evaluate the interference generated by the selected links. The performance of the protocol depends on the number and quality of paths [4]. Disjoint paths are preferred because the nodes are not shared by multiple paths, which may enable packets to be sent over different paths simultaneously [14]. However, to meet QoS requirements and to minimize congestion might require a global view of the network topology [4].

A multipath selection mechanism that adopts disjoint paths more flexible was proposed in [15]. It introduced the concept of quasi-disjoint paths (QD-paths), which is built from a more flexible definition and generally provides one or more additional paths. Results show that this mechanism increases path diversity with low overhead and improves redundancy. However, this work did not consider multiple sources.

The multipath selection problem is proved to be of the NP-hard class [16]. Because of this, heuristics-based solutions to select multiple paths that minimize cost or maximize throughput are considered in [17], but there are still open issues. A heuristic to multipath selection for video streaming that takes into account the self-interference between links over an ad hoc wireless network was proposed in [18]. The method, called PDP (packet drop probability) aware multipath routing protocol, estimates the probability of packet loss to select the best paths and improve performance, but assumes the existence of disjoint paths between nodes.

Video-surveillance systems have specific QoS requirements such as high throughput and low latency to allow better resolution and responsiveness. These QoS requirements need more efficient path selection to provide higher bandwidth and better load balancing. Several studies have proposed a cross-layer approach between the application layer and the network layer for multipath video coding transport seeking to improve reliability. MDC is consider ideal for these proposals because it allows descriptions to be transmitted independently through different paths and to improve the aggregate throughput [15].

Recovery of free-viewpoint video for wireless multipath streaming using MDC was proposed in [6], with a joint interview and temporal description recovery capability. The texture and depth signals of two camera-captured viewpoints are encoded into two independently decodable descriptions and transmitted through two disjoint paths. This proposal can outperform a single description/single path streaming solution but considered only two sources.

A reference-frame-cache-based surveillance video transmission system (RSVTS), which delivers wide-viewing-angle and high-definition surveillance video over the internet in real-time using multiple rotatable cameras, was presented in [9]. They implement a reference frame cache on both the sender and receiver sides to improve the video. However, this proposal could exploit the multipath routing protocol to increase network performance.

In general, existing proposals do not exploit mechanisms that consider a global view of the network, where link quality is affected by self-interference. In addition, few studies focus on the video-surveillance system, where multiple sources transmit to a sink. In the following section, we present a specific multipath selection mechanism for video-surveillance systems that considers the video coding and aggregate network throughput.

## IV. ILS-MDC

Metaheuristics are still not fully explored for multipath selection for video-surveillance systems, but they are an alternative to improve the performance of similar solutions in network problems [19] [20].

Iterated Local Search (ILS), in special, has been used to solve problems involving the selection of multiple paths with high efficiency for other application areas [8]. Its iterative nature that continuously seeks to improve a set of solutions can also be effective for the selection of multiple paths for multiple sources.

In this paper, we propose the multipath selection mechanism called ILS-MDC. This mechanism is based on the ILS metaheuristic to select better paths for MDC with multiple sources considering inter-flow interference. Our goal is to maximize the aggregate network throughput to improve the QoS of the wireless video-surveillance systems.

### *A. Iterated Local Search (ILS)*

ILS has been presented as one of the best heuristic alternatives to solve different combinatorial optimization problems of the NP-complete class [8]. Its efficiency and simplicity is demonstrated to solve network routing problems by [20], [21] and [22].

Algorithm 1 shows the ILS procedures which consist of: (i) $GenerateInitialSolution\ s_0$; (ii) $LocalSearch$ to refine $s_0$ seeking a better solution $s$; (iii) $Perturbation$ to generate intermediate solutions $s'$ and $s$" and (iv) $AcceptanceCriterion$ which determines if a new solution is accepted. These procedures iterate until the termination condition is met, usually consisting of a limit to the number of iterations without significant improvements and a time criterion to stop the search, according to the application's requirements. The $AcceptanceCriterion$ has a strong influence on the effectiveness of the search in the set of solutions $S$. Thus, it can be used to control the balance between intensification and diversification of that search.

**Algorithm 1:** Iterated Local Search (ILS)

```
Input  : $S$
Output: $s$
begin
    $s_0 \leftarrow GenerateInitialSolution$;
    $s \leftarrow LocalSearch(s_0)$;
    repeat
        $s \leftarrow Perturbation(s, history)$;
        $s'' \leftarrow LocalSearch(s')$;
        $s \Leftarrow AcceptanceCriterion(s, s'', history)$;
    until termination condition met;
end
```

### *B. ILS-MDC Mechanism*

The path discovery mechanism of a routing protocol determines a set of intermediate nodes that should be used to forward packets from the source nodes to the sink. Thus, the ILS-MDC mechanism is responsible to select better paths for each flow of descriptions. The number of descriptions is an input parameter according to the demands of applications.

The ILS-MDC mechanism is based on the ILS procedure and was implemented using AFTER (Algorithmic Framework for Throughput EstimatoRs) [7], an on-the-fly algorithm for real-time throughput estimate for multihop IEEE 802.11 based networks that considers a global view of the network. AFTER works as a deterministic discrete-event simulator for predicting the throughput of each flow for a given set of data flows and corresponding routes. For this, it simulates the behavior of the link and network layers, replacing any stochastic component with its long term expected outcome. With that approach, AFTER is able to rapidly converge to a stable simulation state that allows it to make accurate estimates of the long-term average throughput for each flows in autonomic fashion [7].

The ILS-MDC mechanism receives as inputs a graph representing the network topology, a list $F$ of the nodes that will act as video sources, the identification of the sink node, and a list $D$ with the number of descriptions for each source. Figure 3 shows an example of a network topology with two video sources represented by nodes 0 and 1 and a sink represented by node 8. In this case, if the application requires two descriptions for each source then it is necessary to select the four best paths so that two flows are transmitted for each video source. The following are the details of each ILS-MDC procedure implemented to select the paths.

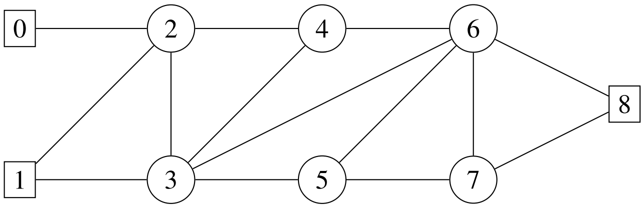

Fig. 3. Example network topology used to illustrate ILS-MDC

*1) Initial Solution:* An initial solution is generated by the $GenerateCandidates$ procedure. This procedure takes as input a network topology represented by a graph $G(N, L)$ where $N$ is a set of nodes $\{0, 1...n\}$ and $L$ is a set of link $\{0, 1...l\}$. It returns a matrix $s_{F \times D}$, where $F$ is the number of sources and $D$ is the maximum number of descriptions required for source. The graph $G$ is created by the route discovery mechanism which evaluates the packet error rate of each link. The initial solution $s_0$ is composed of the shortest paths from each source to the sink based on the $Dijkstra$ algorithm.

Figure 4 illustrates a possible solution $s_0$ obtained for the topology in Figure 3. Each cell of the matrix represents a description path. In this example, the same shortest path is selected for all descriptions of a source, which may cause inter-flow interference and, consequently, lower aggregated network throughput. Thus, the next step attempts to maximize this metric.

$$s_0 = \begin{bmatrix} [0,2,4,6,8] & [0,2,4,6,8] \\ [1,3,6,8] & [1,3,6,8] \end{bmatrix}$$

Fig. 4. Example of initial solution.

*2) Local Search:* The $LocalSearch$ procedure searches the nearest neighbors of the current solution $s$ to get better solutions. For this, each path in solution $s$ is replaced with a new path of the set $S$. Algorithm 2 shows the procedure using the function $newPath$, where $f$ is the source to get a new path.

The candidate solutions are evaluated by the $EstimateThroughput$ procedure of the framework AFTER [7], which analyzes each flow of the selected paths and returns an estimate for the long-term average aggregate network throughput.

**Algorithm 2:** Local Search

```
Input  : $s$
Output: $s$
begin
    $s' \leftarrow s$;
    foreach source $f \in F$ do
        $np \leftarrow newPath(f)$;
        foreach description $d \in D$ do
            $s[f][d] \leftarrow np$;
            if $EstimateThroughput(s') >$
            $EstimateThroughput(s)$ then
                $s \leftarrow s'$;
        end
    end
end
```

*3) Perturbation:* The $Perturbation$ procedure aims to escape from optimal local by applying perturbations to the current local minimum, thus avoiding premature convergence. This procedure, shown in Algorithm 3, was implemented to generate new candidates at each iteration. For this, the procedure randomly replaces one of the $D$ description paths for each of the $F$ sources.

The current solution is perturbed based on the best solution stored in history. This procedure may identify new locals that were not found by a simple shortest path or nearest neighbor.

**Algorithm 3:** Perturbation

```
Input  : $s, history$
Output: $s$
begin
    foreach source $f \in F$ do
        $d \leftarrow rand(0, length(F))$;
        $s[f][d] \leftarrow history[f][d]$;
    end
end
```

*4) Acceptance Criterion:* The $AcceptanceCriterion$ procedure defines a quality criterion of the solution returned by local search $s''$. We can only accept solutions that are better than or close to the best solution previously generated by the algorithm.

While in this work we consider the aggregate throughput as the evaluation metric, other QoS parameters could also be employed in this step.

**Algorithm 4:** Acceptance Criterion

```
Input  : $s, s'', history$
Output: $s$
begin
    if $EstimateThroughput(s'') >$
    $EstimateThroughput(s)$ then
        if $EstimateThroughput(s) >$
        $EstimateThroughput(history)$ then
            $history \leftarrow s$;
        $s \leftarrow s''$;
    else
        if $EstimateThroughput(s'') >$
        $EstimateThroughput(history)$ then
            $history \leftarrow s''$;
    end
end
```

In this proposal, a simple local search with complexity $O(n \cdot log\ n)$ was adopted to be viable in medium processing capacity devices. For each iteration, processing time increases with the number of available paths. Notice, however, that for more complex instances it is possible to use the initial solutions to start transmitting the video description flows, while ILS-MDC keeps running in the background, attempting to improve the current path selection. As new, better solutions are found, the forwarding of the flows becomes more efficient, thus improving performance over time.

## V. PERFORMANCE EVALUATION

In this section, we present results of various simulations performed in order to assess the ability of ILS-MDC to improve the aggregate network throughput, in the context of wireless video-surveillance systems. For these simulations, we use the scenario of the urban area shown in Figure 1, which consists of 54 camera nodes and 1 central node, considering camera deployments at each corner of a neighborhood in the city of Niterói.

## A. Experimental environment and setup

The network topology used for the experiments was created by estimating the Packet Error Rate (PER) of each link based on the distance and the Extended Hata-SRD propagation model [23], which is ideal for short-range devices and non-Line-of-Sight (Non-LoS) communication in typical urban environments.

This evaluation aims to show the aggregate network throughput gain of ILS-MDC in relation to the shortest path solution and how this gain increases over time. For this, two types of monitoring scenarios were simulated: (i) Streets - to follow a target along a street and (ii) Blocks - to follow a target around a block. For each of the 9 streets and 12 blocks of the urban region, instances were created with different numbers of video source descriptions. The parameters of these instances are shown in Table I.

TABLE I
EXPERIMENT PARAMETERS

| Video Sources | Descriptions for each Source | Total Number of Paths |
|---|---|---|
| 2 | 2 | 4 |
| 2 | 3 | 6 |
| 4 | 2 | 8 |
| 4 | 3 | 12 |
| 8 | 2 | 16 |
| 8 | 3 | 24 |

As the acceptance criterion, we adopted a limit of 100 iterations without improvement. The execution of the mechanism was also limited to 90 seconds, considering a maximum waiting time to improve transmission performance.

## B. Results

Our results are presented through two analysis. The first one aims to show the ILS-MDC aggregated network throughput gain while the second shows how this gain was achieved over time. These analysis were performed with a different number of sources and descriptions, according to Table I, and are shown for both Street and Block scenarios.

Figure 5 shows the average percentage gain of ILS-MDC in terms of aggregate throughput. This relative gain to the shortest path that was adopted as ILS-MDC's initial solution [15]. The gain oscillated between 28% and 33% for all experiments. For 4 sources, there was a larger gain due to the better diversity of paths, whereas for 2 sources the shortest path already achieved good solutions and for 8 sources the number of paths tends to congest the network. That last phenomenon also happens with 3 descriptions. For the Street scenario, there are more representative gains for 2 and 4 sources, since shortest paths tend to increase congestion. This is because the cameras are close to each other along the street and their transmissions share nodes and links along the paths. For 8 sources, the same congestion remains for both scenarios due to a lower diversity of paths.

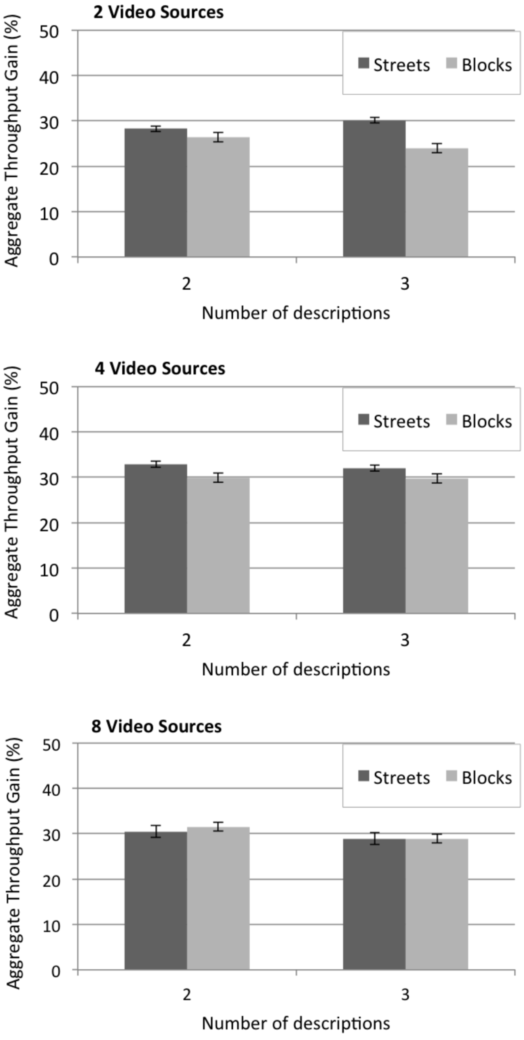

Fig. 5. Average aggregate network throughput gains with ILS-MDC.

ILS-MDC can be implemented in multipath routing protocols with different network technologies. If we consider a suitable standard for WMSNs, such as IEEE 802.11n assuming a transmission rate of up to 300 Mb/s and 1500-byte packets, these average gains obtained by ILS-MDC showed in Figure 5 are equivalent an aggregate throughput gain 19 Mb/s and 30 Mb/s in comparison to the simple use of shortest paths.

Figure 6 shows how this gain increases over time. For this, we divided the average gain of all experiments with the same parameters and scenarios into 10-time steps and we plotted the average gain achieved at each step. Each graphic was generated with different numbers of $P$ distinct paths. Therefore, we considered combinations of 2 and 3 descriptions for each source. According to the complexity of the mechanism, we can see that the time intervals increase according to the number of selected paths.

We can see that the gains obtained in the Block scenario were faster than those in the Street scenario since the cameras are better distributed geographically, favoring convergence in

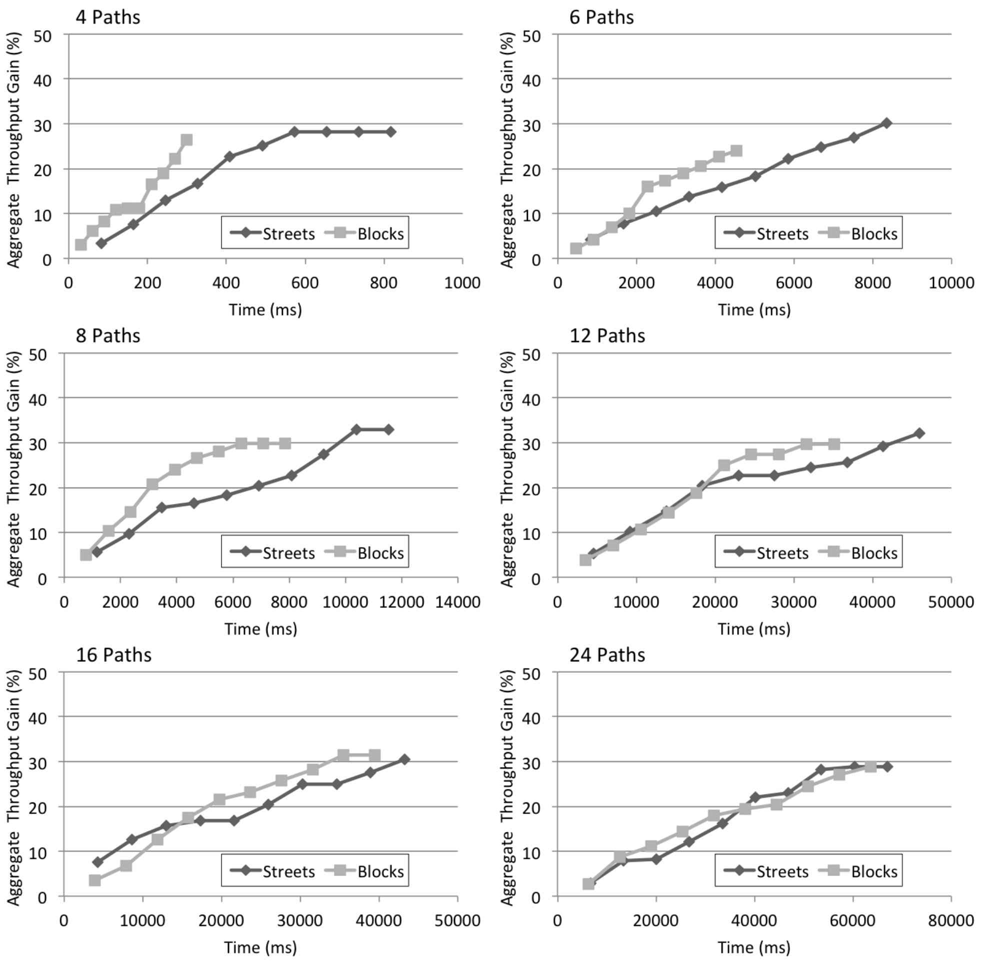

Fig. 6. Average aggregate network throughput gains over time.

the initial iterations. When we have a better set of solutions, such as similar paths and costs, convergence is faster because it finds the better paths in local searches. However, as the number of required paths increases, it is necessary to search for alternative paths. This is one of the main features of the ILS-MDC mechanism that aims to escape from optimal local by applying perturbations to the current local minimum. In this case, we can see that by increasing the number of paths, both scenarios become more similar over time. They need to perform more perturbations because the paths use the same nodes and links that cause congestion.

## VI. CONCLUSION

Transmitting multiple video sources using MDC with multipath routing protocol can improve wireless video-surveillance system's QoS. For this, it is necessary to implement a multipath selection mechanism that identifies better paths with lower inter-flow interference. However, that is a hard computational task due to the large solution space.

We presented the ILS-MDC, a multipath selection mechanism based on the Iterated Local Search metaheuristic, to select better paths for multiple video sources using MDC, considering a global network view. Simulation results show a significant improvement in aggregate throughput when compared to the shortest paths and demonstrate the potential of ILS-MDC to increase the QoS for video-surveillance systems.

For future work, we intend to implement extended versions of ILS-MDC for local search with different neighborhood structures, generating hybrid heuristics such as ILS/VND or ILS/RVND, as suggested in [20] and [22]. In addition, we intend to include the investigation of hybrid algorithms where part of the local search is performed by exact optimization methods, known as matheuristics [20]. We also intend to implement an acceptance criteria to consider specific parameters of the QoS requirements for video-surveillance systems. Finally, we intend to compare the ILS-MDC mechanism with implementations of existing multipath routing protocols over wireless multimedia sensor networks.

## REFERENCES

[1] M. Usman, N. Yang, M. A. Jan, X. He, M. Xu, and K. Lam, "A joint framework for QoS and QoE for video transmission over wireless multimedia sensor networks," *IEEE Transactions on Mobile Computing*, vol. 17, no. 4, pp. 746–759, April 2018.

[2] H. Shen and G. Bai, “Routing in wireless multimedia sensor networks: A survey and challenges ahead,” *Journal of Network and Computer Applications*, vol. 71, pp. 30–49, 2016.

[3] S. A. Alvi, B. Afzal, G. A. Shah, L. Atzori, and W. Mahmood, “Internet of multimedia things: Vision and challenges,” *Ad Hoc Networks*, vol. 33, pp. 87–111, 2015.

[4] M. Z. Hasan, H. Al-Rizzo, and F. Al-Turjman, “A survey on multipath routing protocols for QoS assurances in real-time wireless multimedia sensor networks,” *IEEE Communications Surveys & Tutorials*, vol. 19, no. 3, pp. 1424–1456, 2017.

[5] M. Ghareeb and C. Viho, “Hybrid QoE assessment is well-suited for multiple description coding video streaming in overlay networks,” in *Eighth Annual Communication Networks and Services Research Conference (CNSR)*. IEEE, 2010, pp. 327–333.

[6] Z. Liu, G. Cheung, J. Chakareski, and Y. Ji, “Multiple description coding and recovery of free viewpoint video for wireless multi-path streaming,” *IEEE Journal of Selected Topics in Signal Processing*, vol. 9, no. 1, pp. 151–164, 2015.

[7] D. Passos and C. Albuquerque, “AFTER: Algorithmic Framework for Throughput EstimatoRs for IEEE 802.11 networks,” *Simulation Modelling Practice and Theory*, vol. 84, pp. 143–160, 2018.

[8] H. R. Lourenço, O. C. Martin, and T. Stützle, “Iterated local search: Framework and applications,” in *Handbook of metaheuristics*. Springer, 2010, pp. 363–397.

[9] M. Wang, B. Cheng, and C. Yuen, “Joint coding-transmission optimization for a video surveillance system with multiple cameras,” *IEEE Transactions on Multimedia*, vol. 20, no. 3, pp. 620–633, March 2018.

[10] P. Natarajan, P. K. Atrey, and M. Kankanhalli, “Multi-camera coordination and control in surveillance systems: A survey,” *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)*, vol. 11, no. 4, p. 57, 2015.

[11] V. K. Goyal, “Multiple description coding: Compression meets the network,” *IEEE Signal Processing Magazine*, vol. 18, no. 5, pp. 74–93, 2001.

[12] Y. Wang, A. R. Reibman, and S. Lin, “Multiple description coding for video delivery,” *Proceedings of the IEEE*, vol. 93, no. 1, pp. 57–70, 2005.

[13] A. C. Begen, Y. Altunbasak, and O. Ergun, “Multi-path selection for multiple description encoded video streaming,” in *IEEE International Conference on Communications (ICC)*, vol. 3. IEEE, 2003, pp. 1583–1589.

[14] J. G. Apostolopoulos and M. D. Trott, “Path diversity for enhanced media streaming,” *IEEE Communications Magazine*, vol. 42, no. 8, pp. 80–87, 2004.

[15] M. A. Santos, D. E. Porras, R. M. Silveira, and C. B. Margi, “Multipath source routing strategies for video transmission in ad hoc wireless networks,” *Wireless Networks*, vol. 21, no. 3, pp. 859–869, 2015.

[16] Z. Ma, H.-R. Shao, and C. Shen, “A new multi-path selection scheme for video streaming on overlay networks,” in *IEEE International Conference on Communications (ICC)*, vol. 3. IEEE, 2004, pp. 1330–1334.

[17] S. Li, R. K. Neelisetti, C. Liu, and A. Lim, “Efficient multi-path protocol for wireless sensor networks,” *International Journal of Wireless and Mobile Networks*, vol. 2, no. 1, pp. 110–130, 2010.

[18] W. Wei and A. Zakhor, “Interference aware multipath selection for video streaming in wireless ad hoc networks,” *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 19, no. 2, pp. 165–178, 2008.

[19] T. Neves, L. S. Ochi, and C. Albuquerque, “A new hybrid heuristic for replica placement and request distribution in content distribution networks,” *Optimization Letters*, vol. 9, no. 4, pp. 677–692, 2015.

[20] P. H. V. Penna, A. Subramanian, L. S. Ochi, T. Vidal, and C. Prins, “A hybrid heuristic for a broad class of vehicle routing problems with heterogeneous fleet,” *Annals of Operations Research*, pp. 1–70, 2017.

[21] E. A. Lemamou, P. Galinier, and S. Chamberland, “A hybrid iterated local search algorithm for the global planning problem of survivable 4g wireless networks,” *IEEE/ACM Transactions on Networking (TON)*, vol. 24, no. 1, pp. 137–148, 2016.

[22] M. M. Silva, A. Subramanian, and L. S. Ochi, “An iterated local search heuristic for the split delivery vehicle routing problem,” *Computers & Operations Research*, vol. 53, pp. 234–249, 2015.

[23] ECO/Project SEAMCAT, manual, “Implementation of extended Hata and extended Hata-SRD models.” [Online]. Available: https://ecocfl.cept.org/display/SH/A17.3+EXTENDED+HATA+MODEL