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Research Article

Prime Labeling of Mobius Ladder Graphs M_n

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Abstract

Graph labeling, in which integers are assigned to the vertices or edges of a graph subject to given conditions, is an active area of graph theory, and prime labeling is one of its well-studied variants. Let $G = (V, E)$ be a graph with vertex set V and edge set E. A graph G is said to have a prime labeling if its vertices can be labeled with distinct integers from $1, 2, \ldots, |V|$ such that for every edge xy in G, the labels assigned to x and y are relatively prime or coprime. A graph is called prime if it has a prime labeling. The Mobius ladder M_n is the graph on $2n$ vertices ($n \geq 3$) formed by two paths $v_0, v_1, \ldots, v_{n-1}$ and $u_0, u_1, \ldots, u_{n-1}$, the n rungs $v_i u_i$, and the two crossing edges $u_{n-1}v_0$ and $v_{n-1}u_0$. Seoud and Youssef proved that M_n is not prime for even n. In this paper, we study the prime labeling of the Mobius ladder M_n for odd n. We first show that M_3 is not prime. We then define explicit labeling functions for sixteen classes of odd n and prove that each function is a prime labeling by means of simple sufficient conditions for two labels to be coprime, for example that one label equals 1, that their sum is prime, or that their difference is 1 or a suitable prime power. Examples of the resulting labelings are illustrated in figures. Since every odd n with $5 \leq n \leq 2001$ belongs to at least one of these classes, we conclude that M_n is prime for every odd n such that $5 \leq n \leq 2001$. Finally, we conjecture that M_n is prime for all odd $n \geq 5$.

Keywords

Prime Labeling, Coprime, Prime Graph, Mobius Ladder

1. Introduction

We consider only finite undirected graphs without loops or multiple edges. Let $G = (V, E)$ be a graph with vertex set V and edge set E.

A graph G is said to have a prime labeling if its vertices can be labeled with distinct integers from $1, 2, \ldots, |V|$ such that for every edge xy in G, the labels assigned to x and y are relatively prime or coprime. A graph is called prime if it has a prime labeling. This concept was originated with Entringer and introduced by Tout, Dabboucy, and Howalla[1].

Around 1980 Entringer conjectured that all trees are prime. Fu and Huang [2] proved that every tree with $n \leq 15$ vertices is prime. O. Pikhurko [12] extended this result to all $n \leq 50$. Other prime graphs include all cycles and the disjoint union of C_{2k} and C_n. Seoud, Diab, and Eisakhans [8] showed that following graphs are prime: Fans, Helms, Flowers, Stars, $K_{2,n}$ and $K_{3,n}$ unless $n = 3$ or 7. They also showed that $P_n + \bar{K}_m (m \geq 3)$ are not prime.The authors [5–7] proved that the following graphs are prime: generalized Petersen graph $P(n, 1)$ for even $n \leq 2500$

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and not prime for odd n , Knodel graphs W3,n for $n \leq 130$ and generalized Petersen graphs $P(n,3)$ are not prime for odd n, prime for even $n \leq 100$. We refer the readers to the dynamic survey by Gallian [3].

The Mobius ladder M_n is defined to be a graph on $2n(n \geq 3)$ vertices with $V(M_n) = \{v_i, u_i : 0 \leq i \leq n-1\}$ and $E(M_n) = \{v_i v_{i+1}, u_i u_{i+1} : 0 \leq i \leq n-2\} \cup \{v_i u_i : 0 \leq i \leq n-1\} \cup \{u_{n-1}v_0, v_{n-1}u_0\}$. M. A. Seoud and Youssef [9] proved that the Mobius ladder M_n is not prime for even n. In this paper, we show that M_n is prime for all odd n.

We will prove the following Theorem by Lemmas 1 - 17.

2. Main Results

Theorem 1. M_n is prime for odd $n \in \mathcal{N} \cup \mathcal{N}^*$.

Observation 1. $f(u)$ and $f(v)$ are coprime if they satisfy any one of the following conditions:

(1) $f(u) = 1$ or $f(v) = 1$,
(2) $f(u) + f(v)$ is prime,
(3) $|f(u) - f(v)| = 1$,
(4) $|f(u) - 2f(v)| = 1$,
(5) $|f(u) - 2f(v)| = 2$ and $f(v)$ is odd,
(6) $|f(u) - f(v)| = p^t$ is a prime power and $f(u) \not\equiv 0 \bmod p$.

Here and throughout, mod denotes modulo.

Lemma 1. M_n is not prime for $n = 3$.

Proof. By contradiction. Let f be a prime labeling of M_3. Without loss of generality, we may assume that $f(v_0) = 6$. Let $N(v_0) = \{u_0, u_2, v_1\}$ be the open neighborhood of v_0. There are only two integers in $\{1,2,3,4,5,6\}$, namely 1 and 5, which are coprime with 6. Hence, at least one vertex of $N(v_0)$ has to be assigned to one integer of $\{2,3,4\}$, a contradiction to the definition of the prime labeling. □

Lemma 2. M_n is prime for odd $n \in \mathcal{N}_1^*$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

Let

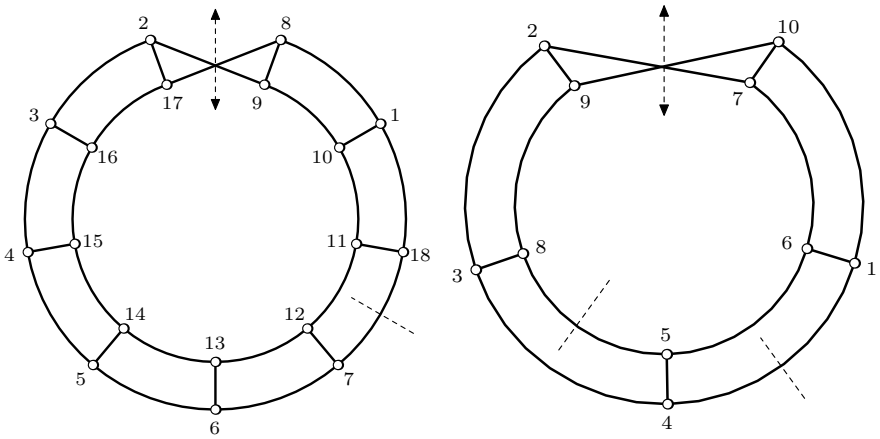
$$f(v_i) = \begin{cases} i+2, & 0 \leq i \leq n-4, \\ 2n, & i = n-3, \\ 1, & i = n-2, \\ n-1, & i = n-1, \end{cases}$$

$$f(u_i) = 2n - i - 1, \qquad 0 \leq i \leq n-1.$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \leq i \leq n-3, \\ 1, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-1, & 0 \leq i \leq n-4, \\ n, & i = n-3, \\ n+1, & i = n-2, \\ n+2, & i = n-1. \end{cases}$$



$M_9,\ 9 \in \mathcal{N}_1^*$ (a) $M_5,\ 5 \in \mathcal{N}_1^*$ (b)

(a) $n \equiv 0 \pmod 3$. (b) $n \not\equiv 0 \pmod 3$.

Figure 1. *Prime labeling of M_n, where $n \equiv 0 \pmod 3$ and $n \not\equiv 0 \pmod 3$.*

In Figure 1a, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}_1^*$ and $n \equiv 0 \bmod 3$. In Figure 1b, we show a prime labeling of M_n, where $n = 5 \in \mathcal{N}_1^*$ and $n \not\equiv 0 \bmod 3$.

Now, we verify that the f is a prime labeling for odd $n \in \mathcal{N}_1^*$ and $n \equiv 0 \bmod 3$.

For $0 \le i \le n-5$, $|f(v_{i+1}) - f(v_i)| = |(i+3)-(i+2)| = 1$, by Observation 1(4), $f(v_i)$ and $f(v_{i+1})$ are coprime. For $i = n-4$, $f(v_{n-4}) = n-2$ and $|f(v_{n-3}) - 2f(v_{n-4})| = |2n-2(n-2)| = 2^2$, so by Observation 1(6), $f(v_{n-4})$ and $f(v_{n-3})$ are coprime. For $i = n-3, n-2$, since $f(v_{n-2}) = 1$, by Observation 1(1), $f(v_i)$ and $f(v_{i+1})$ are coprime. For $i = n-1$, $|f(u_0) - f(v_{n-1})| = |(2n-1) - 2(n-1)| = 1$, by Observation 1(5), $f(v_{n-1})$ and $f(u_0)$ are coprime.

For $0 \le i \le n-2$, $|f(u_i) - f(u_{i+1})| = |(2n-i-1) - (2n-i-2)| = 1$, by Observation 1(4), $f(u_i)$ and $f(u_{i+1})$ are coprime. For $i = n-1$, $f(v_0) = 2$ and $f(u_{n-1}) = n$ is odd, by Observation 1(2), $f(u_{n-1})$ and $f(v_0)$ are coprime.

For $0 \le i \le n-4$, $|f(v_i) + f(u_{i+1})| = |(i+2) + (2n-i-1)| = 2n+1$ is prime($n \in \mathcal{N}_1^*$), so by Observation 1(3), $f(v_i)$ and $f(u_i)$ are coprime. For $i = n-3$, $|f(v_{n-3}) - 2f(u_{n-3})| = |2n-2(n+2)| = 2^2$, by Observation 1(6), $f(v_{n-3})$ and $f(u_{n-3})$ are coprime. For $i = n-2$, $f(v_{n-2}) = 1$, by Observation 1(1), $f(v_{n-2})$ and $f(u_{n-2})$ are coprime. For $i = n-1$, $|f(v_{n-1}) - f(u_{n-1})| = |(n-1) - n| = 1$, so by Observation 1(4), $f(v_{n-1})$ and $f(u_{n-1})$ are coprime.

Hence f is a prime labeling of M_n for odd $n \in \mathcal{N}_1^*$ and $n \equiv 0 \bmod 3$. By a similar argument, we can prove that f is a prime labeling for odd $n \in \mathcal{N}_1^*$ and $n \not\equiv 0 \bmod 3$.

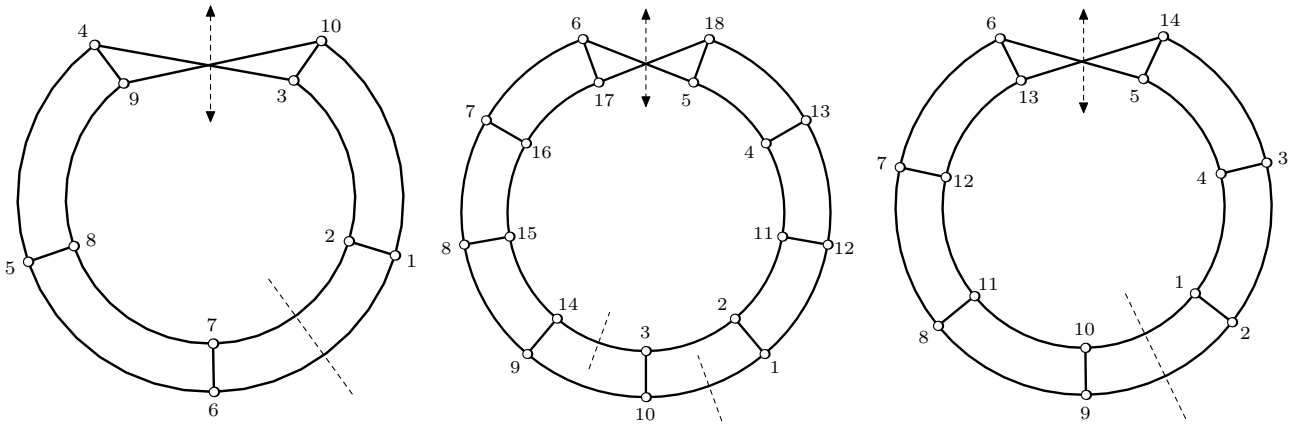
For the Lemmas 3 - 17, we only define f, and by an argument similar to the one in the proof of Lemma 2, we have that f is a prime labeling of M_n.

Lemma 3. M_n is prime for odd $n \in \mathcal{N}_3^*$.

Proof. We define the function f as follows:

Let

$$f(v_i) = \begin{cases} i+4, & 0 \le i \le n-3, \\ 1, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-1, & 0 \le i \le n-3, \\ 2, & i = n-2, \\ 3, & i = n-1. \end{cases}$$



$M_5,\ 5 \in \mathcal{N}_3^*$ (a)

(a) $n = 5 \in \mathcal{N}_3^*$.

$M_9,\ 9 \in \mathcal{N}_5^*$ (b)

(b) $n = 9 \in \mathcal{N}_5^*$.

$M_7,\ 7 \in \mathcal{N}_5^*$ (c)

(c) $n = 7 \in \mathcal{N}_5^*$.

Figure 2. *Prime labeling of M_n, where $n = 5 \in \mathcal{N}_3^*$, $n = 9 \in \mathcal{N}_5^*$ and $n = 7 \in \mathcal{N}_5^*$.*

In Figure 2a, we show a prime labeling of M_n, where $n = 5 \in \mathcal{N}_3^*$.

□

Lemma 4. M_n is prime for odd $n \in \mathcal{N}_5^*$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+6, & 0 \le i \le n-5, \\ 1, & i = n-4, \\ n+3, & i = n-3, \\ n+4, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-1, & 0 \le i \le n-6, \\ 3, & i = n-5, \\ 2, & i = n-4, \\ n+2, & i = n-3, \\ 4, & i = n-2, \\ 5, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+6, & 0 \le i \le n-4, \\ 2, & i = n-3, \\ 3, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-1, & 0 \le i \le n-4, \\ 1, & i = n-3, \\ 4, & i = n-2, \\ 5, & i = n-1, \end{cases}$$

In Figure 2b, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}_5^*$ and $n \equiv 0 \bmod 3$. In Figure 2c, we show a prime labeling of M_n, where $n = 7 \in \mathcal{N}_5^*$ and $n \not\equiv 0 \bmod 3$.

Lemma 5. M_n is prime for odd $n \in \mathcal{N}_7^*$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

□

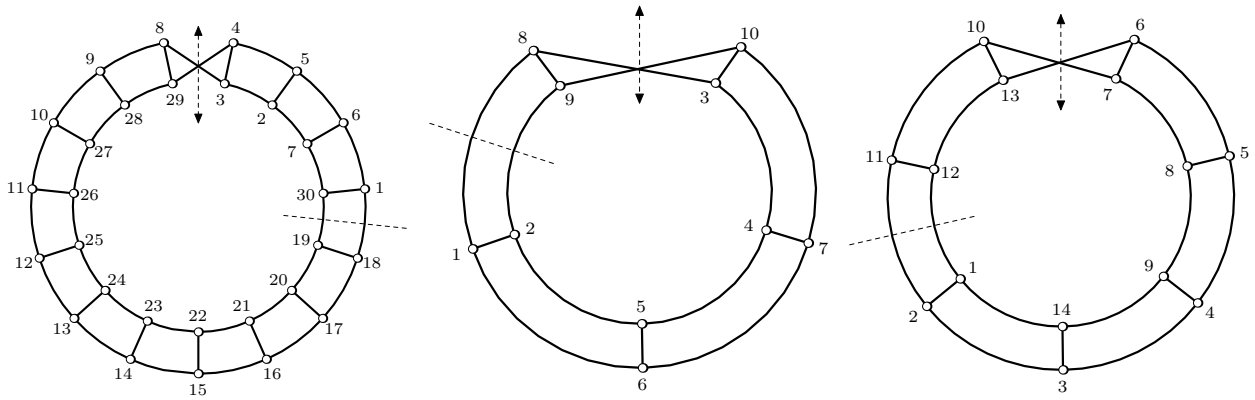
Let

$$f(v_i) = \begin{cases} i+8, & 0 \le i \le n-5, \\ 1, & i = n-4, \\ 6, & i = n-3, \\ 5, & i = n-2, \\ 4, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-1, & 0 \le i \le n-5, \\ 2n, & i = n-4, \\ 7, & i = n-3, \\ 2, & i = n-2, \\ 3, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+8, & 0 \le i \le n-5, \\ 1, & i = n-4, \\ 6, & i = n-3, \\ 7, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-1, & 0 \le i \le n-5, \\ 2, & i = n-4, \\ 5, & i = n-3, \\ 4, & i = n-2, \\ 3, & i = n-1. \end{cases}$$



$M_{15}, 15 \in \mathcal{N}_7^*$ $M_5, 5 \in \mathcal{N}_7^*$ $M_7, 7 \in \mathcal{N}_9^*$

(a) (b) (c)

(a) $n = 15 \in \mathcal{N}_7^*$. (b) $n = 5 \in \mathcal{N}_7^*$. (c) $n = 7 \in \mathcal{N}_9^*$.

Figure 3. *Prime labeling of M_n, where $n = 15 \in \mathcal{N}_7^*$, $n = 5 \in \mathcal{N}_7^*$ and $n = 7 \in \mathcal{N}_9^*$.*

In Figure 3a, we show a prime labeling of M_n, where $n = 15 \in \mathcal{N}_7^*$ and $n \equiv 0 \bmod 3$. In Figure 3b, we show a prime labeling of M_n, where $n = 5 \in \mathcal{N}_7^*$ and $n \not\equiv 0 \bmod 3$.

□

Lemma 6. M_n is prime for odd $n \in \mathcal{N}_9^*$.

Proof. We define the function f as follows:

Case 1. $n \equiv 1 \bmod 3$.

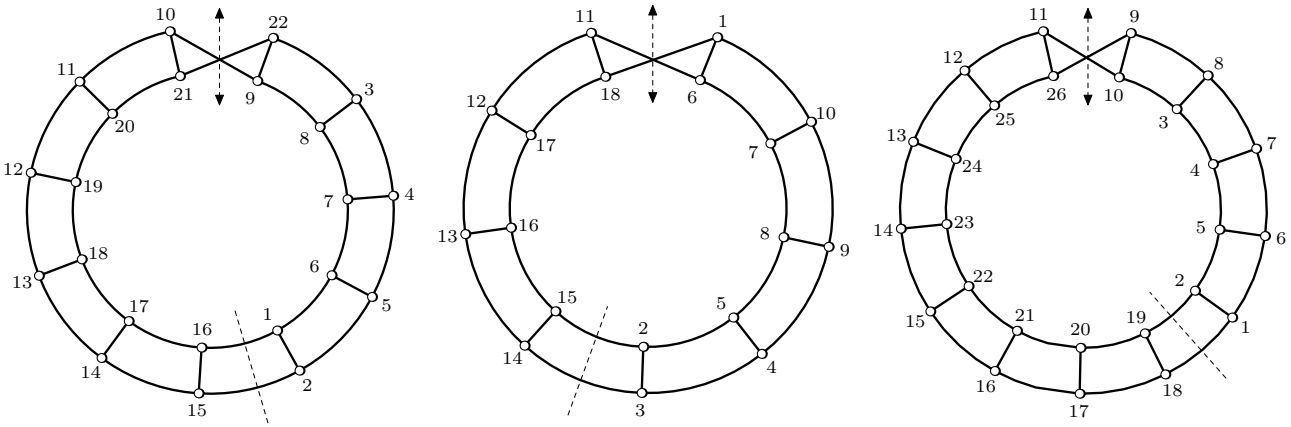
Let

$$f(v_i) = \begin{cases} i+10, & 0 \le i \le n-6, \\ 2, & i = n-5, \\ 3, & i = n-4, \\ 4, & i = n-3, \\ 5, & i = n-2, \\ 6, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-1, & 0 \le i \le n-6, \\ 1, & i = n-5, \\ 2n, & i = n-4, \\ 9, & i = n-3, \\ 8, & i = n-2, \\ 7, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 1 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+10, & 0 \le i \le n-6, \\ 2, & i = n-5, \\ 5, & i = n-4, \\ 4, & i = n-3, \\ 3, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-1, & 0 \le i \le n-6, \\ 1, & i = n-5, \\ 6, & i = n-4, \\ 7, & i = n-3, \\ 8, & i = n-2, \\ 9, & i = n-1. \end{cases}$$



M_{11},11 $\in \mathcal{N}_9^*$ M_9, 9 $\in \mathcal{N}_{11}^*$ M_{13}, 13 $\in \mathcal{N}*_{11}$

(a) (b) (c)

(a) $n = 11 \in \mathcal{N}_9^*$. (b) $n = 9 \in \mathcal{N}_{11}^*$. (c) $n = 13 \in \mathcal{N}_{11}^*$.

Figure 4. *Prime labeling of M_n, where $n = 11 \in \mathcal{N}_9^*$, $n = 9 \in \mathcal{N}_{11}^*$ and $n = 13 \in \mathcal{N}_{11}^*$.*

In Figure 3c, we show a prime labeling of M_n, where $n = 7 \in \mathcal{N}_9^*$ and $n \equiv 1 \bmod 3$. In Figure 4a, we show a prime labeling of M_n, where $n = 11 \in \mathcal{N}_9^*$ and $n \not\equiv 1 \bmod 3$.

□

Lemma 7. M_n is prime for odd $n \in \mathcal{N}_{11}^*$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+11, & 0 \le i \le n-6, \\ 3, & i = n-5, \\ 4, & i = n-4, \\ 9, & i = n-3, \\ 10, & i = n-2, \\ 1, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i, & 0 \le i \le n-6, \\ 2, & i = n-5, \\ 5, & i = n-4, \\ 8, & i = n-3, \\ 7, & i = n-2, \\ 6, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+11, & 0 \le i \le n-6, \\ 1, & i = n-5, \\ 6, & i = n-4, \\ 7, & i = n-3, \\ 8, & i = n-2, \\ 9, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i, & 0 \le i \le n-6, \\ 2, & i = n-5, \\ 5, & i = n-4, \\ 4, & i = n-3, \\ 3, & i = n-2, \\ 10, & i = n-1. \end{cases}$$

In Figure 4b, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}_{11}^*$ and $n \equiv 0 \bmod 3$. In Figure 4c, we show a prime labeling of M_n, where $n = 13 \in \mathcal{N}_{11}^*$ and $n \not\equiv 0 \bmod 3$.

□

Lemma 8. M_n is prime for odd $n \in \mathcal{N}_{-1}^*$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

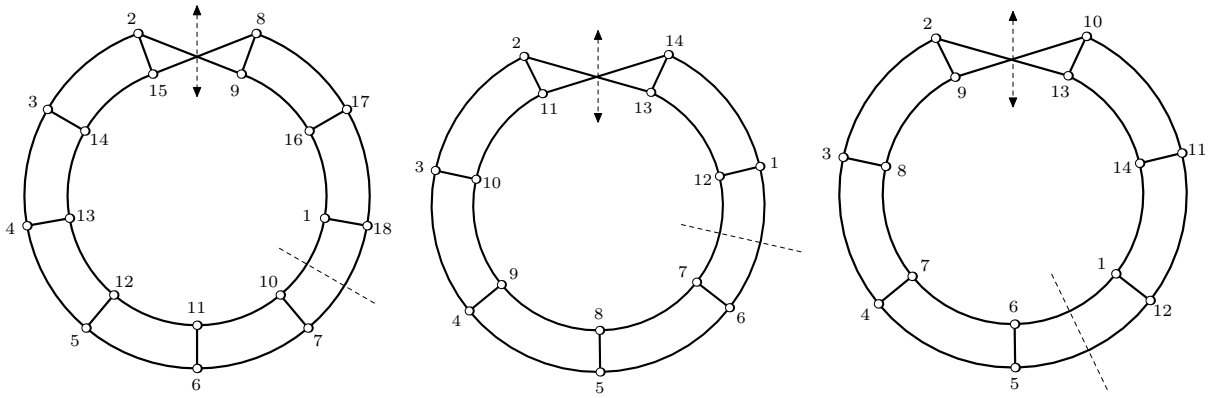
Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-4, \\ 2n, & i = n-3, \\ 2n-1, & i = n-2, \\ n-1, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-3, & 0 \le i \le n-4, \\ 1, & i = n-3, \\ 2n-2, & i = n-2, \\ n, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-3, \\ 1, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-3, & 0 \le i \le n-3, \\ 2n-2, & i = n-2, \\ 2n-1, & i = n-1. \end{cases}$$



$M_9,\ 9 \in \mathcal{N}_{-1}^*$ (a) $M_7,7 \in \mathcal{N}_{-1}^*$ (b) $M_7,7 \in \mathcal{N}_{-3}^*$ (c)

(a) $n = 9 \in \mathcal{N}_{-1}^*$. (b) $n = 7 \in \mathcal{N}_{-1}^*$. (c) $n = 7 \in \mathcal{N}_{-3}^*$.

Figure 5. *Prime labeling of M_n, where $n = 9 \in \mathcal{N}_{-1}^*$, $n = 7 \in \mathcal{N}_{-1}^*$ and $n = 7 \in \mathcal{N}_{-3}^*$.*

In Figure 5a, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}^*_{-1}$ and $n \equiv 0 \bmod 3$. In Figure 5b, we show a prime labeling of M_n, where $n = 7 \in \mathcal{N}^*_{-1}$ and $n = 7 \in \mathcal{N}^*_{-3}$.

□

Lemma 9. M_n is prime for odd $n \in \mathcal{N}^*_{-3}$.

Proof. We define the function f as follows:

Case 1. $n \equiv 1 \bmod 3$.

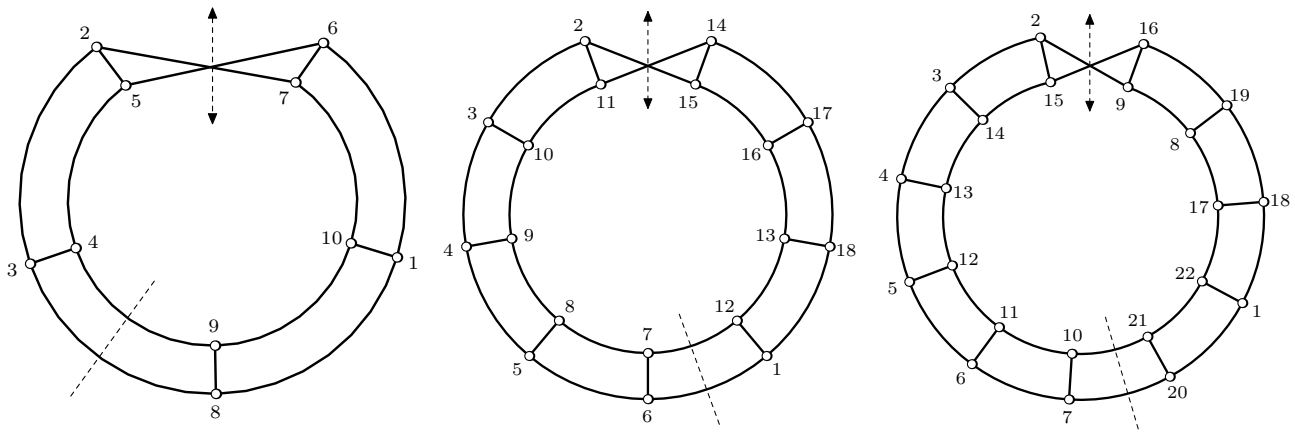
Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-4, \\ 2n-2, & i = n-3, \\ 2n-3, & i = n-2, \\ 2n-4, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-5, & 0 \le i \le n-4, \\ 1, & i = n-3, \\ 2n, & i = n-2, \\ 2n-1, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 1 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-4, \\ 2n-2, & i = n-3, \\ 1, & i = n-2, \\ 2n-4, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-5, & 0 \le i \le n-4, \\ 2n-1, & i = n-3, \\ 2n, & i = n-2, \\ 2n-3, & i = n-1. \end{cases}$$



(a) $n = 5 \in \mathcal{N}^*_{-3}$. (b) $n = 9 \in \mathcal{N}^*_{-5}$. (c) $n = 11 \in \mathcal{N}^*_{-5}$.

Figure 6. *Prime labeling of M_n, where $n = 5 \in \mathcal{N}^*_{-3}$, $n = 9 \in \mathcal{N}^*_{-5}$ and $n = 11 \in \mathcal{N}^*_{-5}$.*

In Figure 5c, we show a prime labeling of M_n, where $n = 7 \in \mathcal{N}^*_{-3}$ and $n \equiv 1 \bmod 3$. In Figure 6a, we show a prime labeling of M_n, where $n = 5 \in \mathcal{N}^*_{-3}$ and $n \not\equiv 1 \bmod 3$.

□

Lemma 10. M_n is prime for odd $n \in \mathcal{N}^*_{-5}$.

*Proof.*In $\mathcal{N}^*_{-5}$, there is only one integer smaller than 9, namely 5. Since $5 \in \mathcal{N}^*_{-3}$, by Lemma 9, M_5 is prime. Hence, we only consider odd $n \ge 9$. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-5, \\ 1, & i = n-4, \\ 2n, & i = n-3, \\ 2n-1, & i = n-2, \\ 2n-4, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-7, & 0 \le i \le n-5, \\ 2n-6, & i = n-4, \\ 2n-5, & i = n-3, \\ 2n-2, & i = n-2, \\ 2n-3, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-6, \\ 2n-2, & i = n-5, \\ 1, & i = n-4, \\ 2n-4, & i = n-3, \\ 2n-3, & i = n-2, \\ 2n-6, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} 2n-i-7, & 0 \le i \le n-6, \\ 2n-1, & i = n-5, \\ 2n, & i = n-4, \\ 2n-5, & i = n-3, \\ n-3, & i = n-2, \\ n-2, & i = n-1. \end{cases}$$

In Figure 6b, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}^*_{-5}$ and $n \equiv 0 \bmod 3$. In Figure 6c, we show a prime labeling of M_n, where $n = 11 \in \mathcal{N}^*_{-5}$ and $n \not\equiv 0 \bmod 3$.

□

Lemma 11. M_n is prime for odd $n \in \mathcal{N}_0$.

Proof. We define the function f as follows:

Case 1. $n \equiv 1 \bmod 3$.

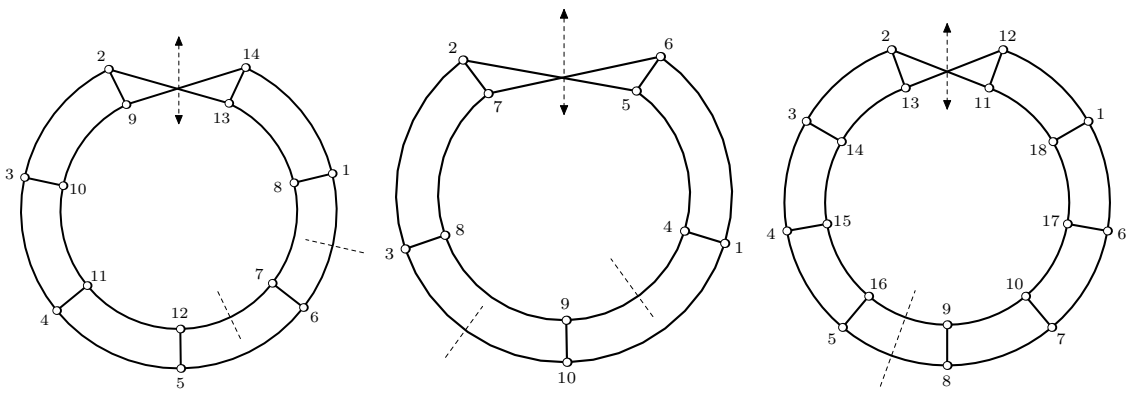
Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-3, \\ 1, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n+2, & 0 \le i \le n-4, \\ n, & i = n-3, \\ n+1, & i = n-2, \\ 2n-1, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 1 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-4, \\ 2n, & i = n-3, \\ 1, & i = n-2, \\ n+1, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n+2, & 0 \le i \le n-3, \\ n-1, & i = n-2, \\ n, & i = n-1. \end{cases}$$



$M_7, 7 \in \mathcal{N}_0$ $M_5, 5 \in \mathcal{N}_0$ $M_9, 9 \in \mathcal{N}_2$

(a) (b) (c)

(a) $n = 7 \in \mathcal{N}_0$. (b) $n = 5 \in \mathcal{N}_0$. (c) $n = 9 \in \mathcal{N}_2$.

Figure 7. *Prime labeling of M_n, where $n = 7 \in \mathcal{N}_0$, $n = 5 \in \mathcal{N}_0$ and $n = 9 \in \mathcal{N}_2$.*

In Figure 7a, we show a prime labeling of M_n, where $n = 7 \in \mathcal{N}_0$ and $n \equiv 1 \bmod 3$. In Figure 7b, we show a prime labeling of M_n, where $n = 5 \in \mathcal{N}_0$ and $n \not\equiv 1 \bmod 3$.

□

Lemma 12. M_n is prime for odd $n \in \mathcal{N}_2$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-6, \\ n-1, & i = n-5, \\ n-2, & i = n-4, \\ n-3, & i = n-3, \\ 1, & i = n-2, \\ n+3, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n+4, & 0 \le i \le n-6, \\ n, & i = n-5, \\ n+1, & i = n-4, \\ 2n-1, & i = n-3, \\ 2n, & i = n-2, \\ n+2, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-2, \\ n+3, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n+4, & 0 \le i \le n-4, \\ 1, & i = n-3, \\ n+1, & i = n-2, \\ n+2, & i = n-1. \end{cases}$$

In Figure 7c, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}_2$ and $n \equiv 0 \bmod 3$. In Figure 8a, we show a prime labeling of M_n, where $n = 5 \in \mathcal{N}_2$ and $n \not\equiv 0 \bmod 3$.

□

Lemma 13. M_n is prime for odd $n \in \mathcal{N}_4$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

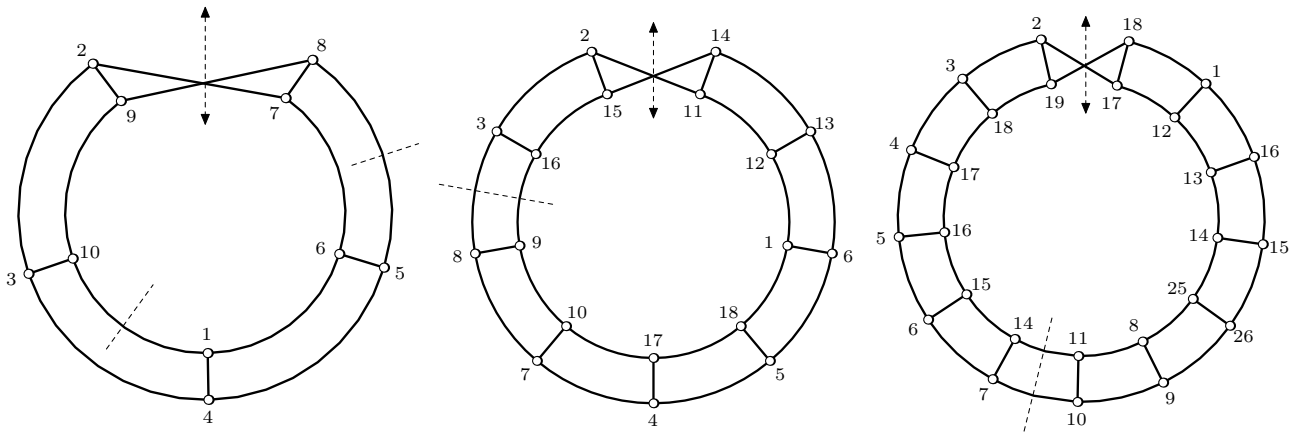
Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-8, \\ n-1, & i = n-7, \\ n-2, & i = n-6, \\ n-5, & i = n-5, \\ n-4, & i = n-4, \\ n-3, & i = n-3, \\ n+4, & i = n-2, \\ n+5, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n+6, & 0 \le i \le n-8, \\ n, & i = n-7, \\ n+1, & i = n-6, \\ 2n-1, & i = n-5, \\ 2n, & i = n-4, \\ 1, & i = n-3, \\ n+3, & i = n-2, \\ n+2, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-8, \\ n-3, & i = n-7, \\ n-4, & i = n-6, \\ 2n, & i = n-5, \\ n+2, & i = n-4, \\ n+3, & i = n-3, \\ 1, & i = n-2, \\ n+5, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} n+i+6, & 0 \le i \le n-8, \\ n-2, & i = n-7, \\ n-5, & i = n-6, \\ 2n-1, & i = n-5, \\ n+1, & i = n-4, \\ n, & i = n-3, \\ n-1, & i = n-2, \\ n+4, & i = n-1. \end{cases}$$



$M_5,\ 5 \in \mathcal{N}_2$ $M_9,\ 9 \in \mathcal{N}_4$ $M_{13},\ 13 \in \mathcal{N}_4$

(a) (b) (c)

(a) $n = 5 \in \mathcal{N}_2$. (b) $n = 9 \in \mathcal{N}_4$. (c) $n = 13 \in \mathcal{N}_4$.

Figure 8. *Prime labeling of M_n, where $n = 5 \in \mathcal{N}_2$, $n = 9 \in \mathcal{N}_4$ and $n = 13 \in \mathcal{N}_4$.*

In Figure 8b, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}_4$ and $n \equiv 0 \bmod 3$. In Figure 8c, we show a prime labeling of M_n, where $n = 13 \in \mathcal{N}_4$ and $n \not\equiv 0 \bmod 3$.

□

Lemma 14. M_n is prime for odd $n \in \mathcal{N}_6$.

Proof. We define the function f as follows:

Case 1. $n \equiv 1 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-8, \\ n+3, & i = n-7, \\ n, & i = n-6, \\ n-3, & i = n-5, \\ n-2, & i = n-4, \\ n-1, & i = n-3, \\ n+6, & i = n-2, \\ n+7, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n+8, & 0 \le i \le n-8, \\ n+2, & i = n-7, \\ n+1, & i = n-6, \\ n-4, & i = n-5, \\ n-5, & i = n-4, \\ 1, & i = n-3, \\ n+5, & i = n-2, \\ n+4, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 1 \bmod 3$.

Case 2.1 $n \equiv 0 \bmod 7$.

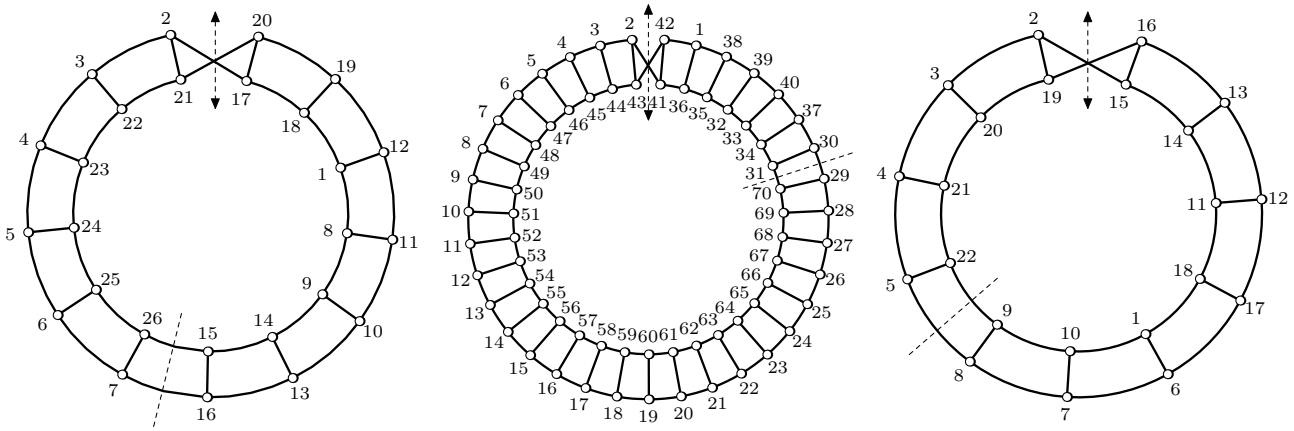
Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-8, \\ n-5, & i = n-7, \\ n+2, & i = n-6, \\ n+5, & i = n-5, \\ n+4, & i = n-4, \\ n+3, & i = n-3, \\ 1, & i = n-2, \\ n+7, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n+8, & 0 \le i \le n-8, \\ n-4, & i = n-7, \\ n-1, & i = n-6, \\ n-2, & i = n-5, \\ n-3, & i = n-4, \\ n, & i = n-3, \\ n+1, & i = n-2, \\ n+6, & i = n-1. \end{cases}$$

Case 2.2. $n \not\equiv 0 \bmod 7$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-8, \\ n-3, & i = n-7, \\ n-4, & i = n-6, \\ n-5, & i = n-5, \\ n+6, & i = n-4, \\ n+1, & i = n-3, \\ n+2, & i = n-2, \\ n+5, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n+8, & 0 \le i \le n-8, \\ n-2, & i = n-7, \\ n-1, & i = n-6, \\ 1, & i = n-5, \\ n+7, & i = n-4, \\ n, & i = n-3, \\ n+3, & i = n-2, \\ n+4, & i = n-1. \end{cases}$$



M_{13}, $13 \in \mathcal{N}_6$ M_{35}, $35 \in \mathcal{N}_6$. M_{11}, $11 \in \mathcal{N}_6$

(a) (b) (c)

(a) $n = 13 \in \mathcal{N}_6$. (b) $n = 35 \in \mathcal{N}_6$. (c) $n = 11 \in \mathcal{N}_6$.

Figure 9. *Prime labeling of M_n, where $n = 13 \in \mathcal{N}_6$, $n = 35 \in \mathcal{N}_6$ and $n = 11 \in \mathcal{N}_6$.*

In Figure 9a, we show a prime labeling of M_n, where $n = 13 \in \mathcal{N}_6$ and $n \equiv 1 \bmod 3$. In Figure 9b, we show a prime labeling of M_n, where $n = 35 \in \mathcal{N}_6$, $n \not\equiv 1 \bmod 3$ and $n \equiv 0 \bmod 7$. In Figure 9c, we show a prime labeling of M_n, where $n = 11 \in \mathcal{N}_6$, $n \not\equiv 1 \bmod 3$ and $n \not\equiv 0 \bmod 7$.

□

Lemma 15. M_n is prime for odd $n \in \mathcal{N}_{-2}$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

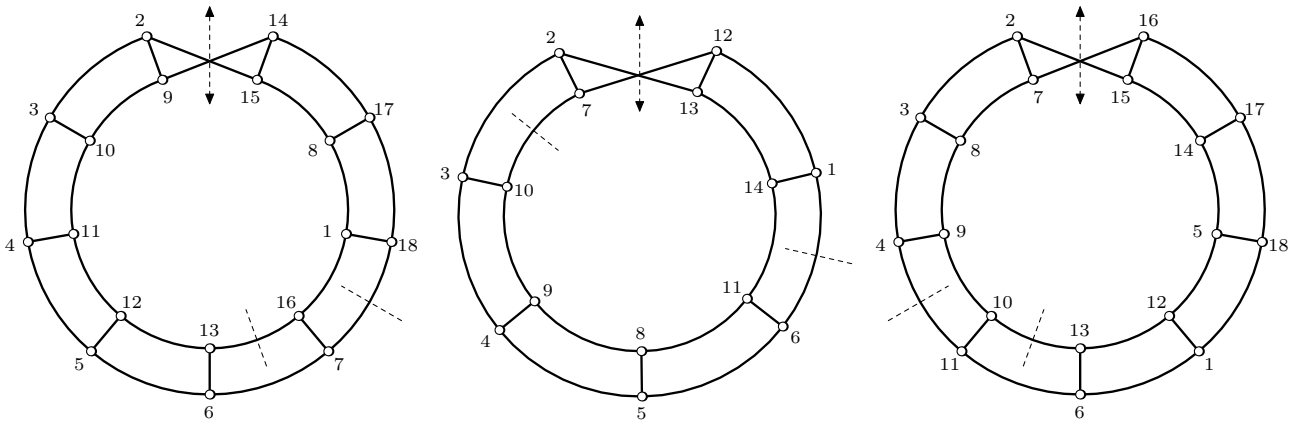
Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-4, \\ 2n, & i = n-3, \\ 2n-1, & i = n-2, \\ 2n-4, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n, & 0 \le i \le n-5, \\ 2n-2, & i = n-4, \\ 1, & i = n-3, \\ n-1, & i = n-2, \\ 2n-3, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-3, \\ 1, & i = n-2, \\ 2n-2, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n, & 0 \le i \le n-7, \\ 2n-4, & i = n-6, \\ 2n-5, & i = n-5, \\ 2n-6, & i = n-4, \\ 2n-3, & i = n-3, \\ 2n, & i = n-2, \\ 2n-1, & i = n-1. \end{cases}$$



(a) $n = 9 \in \mathcal{N}_{-2}$. (b) $n = 7 \in \mathcal{N}_{-2}$. (c) $n = 9 \in \mathcal{N}_{-4}$.

Figure 10. *Prime labeling of M_n, where $n = 9 \in \mathcal{N}_{-2}$, $n = 7 \in \mathcal{N}_{-2}$ and $n = 9 \in \mathcal{N}_{-4}$.*

In Figure 10a, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}_{-2}$ and $n \equiv 0 \bmod 3$. In Figure 10b, we show a prime labeling of M_n, where $n = 7 \in \mathcal{N}_{-2}$ and $n \not\equiv 0 \bmod 3$.

□

Lemma 16. M_n is prime for odd $n \in \mathcal{N}_{-4}$.

Proof. We define the function f as follows:

Case 1. $n \equiv 0 \bmod 3$.

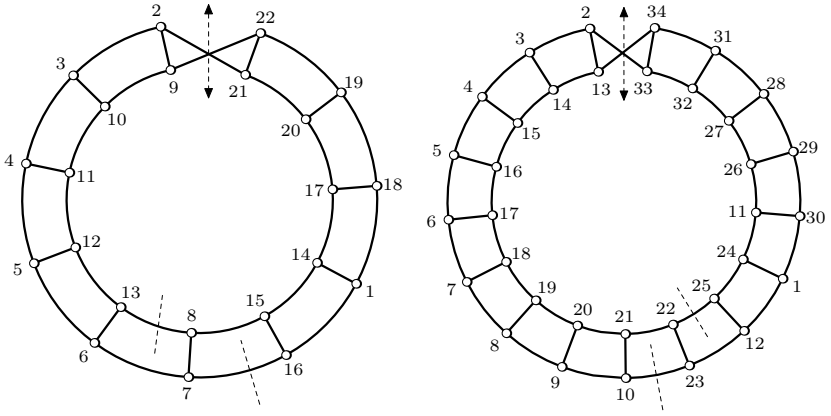
Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-7, \\ 2n-7, & i = n-6, \\ n-3, & i = n-5, \\ 1, & i = n-4, \\ 2n, & i = n-3, \\ 2n-1, & i = n-2, \\ 2n-2, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n-2, & 0 \le i \le n-6, \\ 2n-5, & i = n-5, \\ 2n-6, & i = n-4, \\ n-4, & i = n-3, \\ 2n-4, & i = n-2, \\ 2n-3, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 0 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-6, \\ 2n-6, & i = n-5, \\ 1, & i = n-4, \\ 2n-4, & i = n-3, \\ 2n-3, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n-2, & 0 \le i \le n-7, \\ n-3, & i = n-6, \\ 2n-7, & i = n-5, \\ 2n-8, & i = n-4, \\ 2n-5, & i = n-3, \\ 2n-2, & i = n-2, \\ 2n-1, & i = n-1. \end{cases}$$



(a) $n = 11 \in \mathcal{N}_{-4}$. (b) $n = 17 \in \mathcal{N}_{-6}$.

Figure 11. *Prime labeling of M_n, where $n = 11 \in \mathcal{N}_{-4}$ and $n = 17 \in \mathcal{N}_{-6}$.*

In Figure 10c, we show a prime labeling of M_n, where $n = 9 \in \mathcal{N}_{-4}$ and $n \equiv 0 \bmod 3$. In Figure 11a, we show a prime labeling of M_n, where $n = 11 \in \mathcal{N}_{-4}$ and $n \not\equiv 0 \bmod 3$.

□

Lemma 17. M_n is prime for odd $n \in \mathcal{N}_{-6}$.

Proof. In $\mathcal{N}_{-6}$, there are only one integer not in N_{-6}, namely 11. Since $11 \in \mathcal{N}_{-4}$, by Lemma 16, M_{11} is prime. Hence, we only consider all odd n except 11. We define the function f as follows:

Case 1. $n \equiv 2 \bmod 3$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-9, \\ 2n-11, & i = n-8, \\ n-5, & i = n-7, \\ 1, & i = n-6, \\ 2n-4, & i = n-5, \\ 2n-5, & i = n-4, \\ 2n-6, & i = n-3, \\ 2n-3, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n-4, & 0 \le i \le n-8, \\ 2n-9, & i = n-7, \\ 2n-10, & i = n-6, \\ n-6, & i = n-5, \\ 2n-8, & i = n-4, \\ 2n-7, & i = n-3, \\ 2n-2, & i = n-2, \\ 2n-1, & i = n-1. \end{cases}$$

Case 2. $n \not\equiv 2 \bmod 3$.

Case 2.1. $n \equiv 0 \bmod 5$.

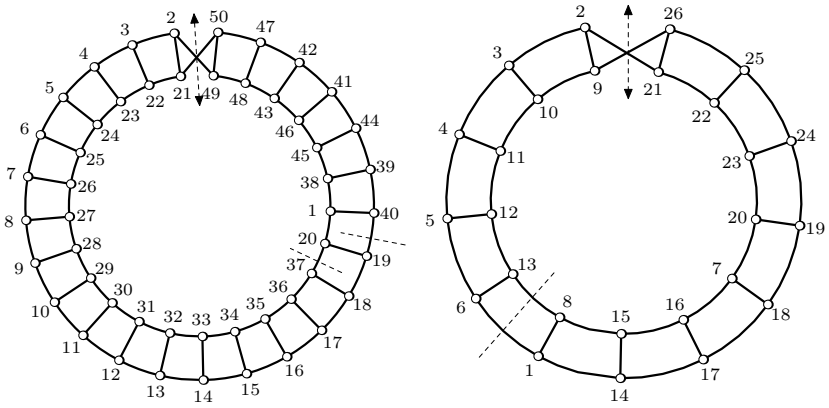
Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-8, \\ 2n-10, & i = n-7, \\ 2n-11, & i = n-6, \\ 2n-6, & i = n-5, \\ 2n-9, & i = n-4, \\ 2n-8, & i = n-3, \\ 2n-3, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n-4, & 0 \le i \le n-9, \\ n-5, & i = n-8, \\ 1, & i = n-7, \\ 2n-12, & i = n-6, \\ 2n-5, & i = n-5, \\ 2n-4, & i = n-4, \\ 2n-7, & i = n-3, \\ 2n-2, & i = n-2, \\ 2n-1, & i = n-1. \end{cases}$$

Case 2.2. $n \not\equiv 0 \bmod 5$.

Let

$$f(v_i) = \begin{cases} i+2, & 0 \le i \le n-9, \\ 1, & i = n-8, \\ 2n-12, & i = n-7, \\ 2n-9, & i = n-6, \\ 2n-8, & i = n-5, \\ 2n-7, & i = n-4, \\ 2n-2, & i = n-3, \\ 2n-1, & i = n-2, \\ 2n, & i = n-1, \end{cases} \qquad f(u_i) = \begin{cases} i+n-4, & 0 \le i \le n-9, \\ n-5, & i = n-8, \\ 2n-11, & i = n-7, \\ 2n-10, & i = n-6, \\ n-6, & i = n-5, \\ 2n-6, & i = n-4, \\ 2n-3, & i = n-3, \\ 2n-4, & i = n-2, \\ 2n-5, & i = n-1. \end{cases}$$



$M_{25},\ 25 \in \mathcal{N}_{-6}.$ $M_{13},\ 13 \in \mathcal{N}_{-6}$

(a) (b)

(a) $n = 25 \in \mathcal{N}_{-6}$. (b) $n = 13 \in \mathcal{N}_{-6}$.

Figure 12. *Prime labeling of* M_n, *where* $n = 25 \in \mathcal{N}_{-6}$ *and* $n = 13 \in \mathcal{N}_{-6}$.

In Figure 11b, we show a prime labeling of M_n, where $n = 17 \in \mathcal{N}_{-6}$ and $n \equiv 2 \bmod 3$. In Figure 12a, we show a prime labeling of M_n, where $n = 25 \in \mathcal{N}_{-6}$, $n \not\equiv 2 \bmod 3$ and $n \equiv 0 \bmod 5$. In Figure 12b, we show a prime labeling of M_n, where $n = 13 \in \mathcal{N}_{-6}$, $n \not\equiv 2 \bmod 3$ and $n \not\equiv 0 \bmod 5$.

□

3. Conclusion

We constructed an explicit prime labeling of Mobius Ladder M_n. From the Lemmas 2 - 17, Theorem 1 holds for any odd n such that $5 \le n \le 2001$. Furthermore, we have the following conjecture

Conjecture 1. M_n is prime for all odd $n \ge 5$.

Since $n \in \mathcal{N} \cup \mathcal{N}^*$ for any odd n such that $5 \le n \le 2001$, by Theorem 1 and Table 1, we have Conjecture 1 holds for odd n such that $5 \le n \le 2001$.

Table 1. *$n \in \mathcal{N} \cup \mathcal{N}^*$ for any odd n such that $5 \le n \le 2001$.*

$n \in \mathcal{N}_i$	$n \in \mathcal{N}_i$	$n \in \mathcal{N}_i$	$n \in \mathcal{N}_i$	$n \in \mathcal{N}_i$	$n \in \mathcal{N}_i$	$n \in \mathcal{N}_i$	$n \in \mathcal{N}_i$	$n \in \mathcal{N}_i$
$5 \in \mathcal{N}_0$	$7 \in \mathcal{N}_0$	$9 \in \mathcal{N}_2$	$11 \in \mathcal{N}_0$	$13 \in \mathcal{N}_0$	$15 \in \mathcal{N}_2$	$17 \in \mathcal{N}_0$	$19 \in \mathcal{N}_0$	$21 \in \mathcal{N}_2$
$23 \in \mathcal{N}_0$	$25 \in \mathcal{N}_{-2}$	$27 \in \mathcal{N}_2$	$29 \in \mathcal{N}_0$	$31 \in \mathcal{N}_0$	$33 \in \mathcal{N}_{-2}$	$35 \in \mathcal{N}_2$	$37 \in \mathcal{N}_0$	$39 \in \mathcal{N}_{-2}$
$41 \in \mathcal{N}_0$	$43 \in \mathcal{N}_0$	$45 \in \mathcal{N}_2$	$47 \in \mathcal{N}_0$	$49 \in \mathcal{N}_{-2}$	$51 \in \mathcal{N}_2$	$53 \in \mathcal{N}_0$	$55 \in \mathcal{N}_{-2}$	$57 \in \mathcal{N}_2$
$59 \in \mathcal{N}_0$	$61 \in \mathcal{N}_0$	$63 \in \mathcal{N}_{-2}$	$65 \in \mathcal{N}_2$	$67 \in \mathcal{N}_0$	$69 \in \mathcal{N}_2$	$71 \in \mathcal{N}_0$	$73 \in \mathcal{N}_0$	$75 \in \mathcal{N}_{-2}$
$77 \in \mathcal{N}_2$	$79 \in \mathcal{N}_0$	$81 \in \mathcal{N}_2$	$83 \in \mathcal{N}_0$	$85 \in \mathcal{N}_{-2}$	$87 \in \mathcal{N}_2$	$89 \in \mathcal{N}_0$	$91 \in \mathcal{N}_{-2}$	$93 \in \mathcal{N}_4$
				...				
				...				
				...				
$1913 \in \mathcal{N}_0$	$1915 \in \mathcal{N}_{-2}$	$1917 \in \mathcal{N}_{-4}$	$1919 \in \mathcal{N}_{-6}$	$1921 \in \mathcal{N}_5^*$	$1923 \in \mathcal{N}_1^*$	$1925 \in \mathcal{N}_6$	$1927 \in \mathcal{N}_4$	$1929 \in \mathcal{N}_2$
$1931 \in \mathcal{N}_0$	$1933 \in \mathcal{N}_0$	$1935 \in \mathcal{N}_{-2}$	$1937 \in \mathcal{N}_{-4}$	$1939 \in \mathcal{N}_{-6}$	$1941 \in \mathcal{N}_{-1}^*$	$1943 \in \mathcal{N}_6$	$1945 \in \mathcal{N}_4$	$1947 \in \mathcal{N}_2$
$1949 \in \mathcal{N}_0$	$1951 \in \mathcal{N}_0$	$1953 \in \mathcal{N}_{-2}$	$1955 \in \mathcal{N}_{-4}$	$1957 \in \mathcal{N}_{-6}$	$1959 \in \mathcal{N}_{-1}^*$	$1961 \in \mathcal{N}_{-3}^*$	$1963 \in \mathcal{N}_{-3}^*$	$1965 \in \mathcal{N}_{-1}^*$
$1967 \in \mathcal{N}_6$	$1969 \in \mathcal{N}_4$	$1971 \in \mathcal{N}_2$	$1973 \in \mathcal{N}_0$	$1975 \in \mathcal{N}_{-2}$	$1977 \in \mathcal{N}_2$	$1979 \in \mathcal{N}_0$	$1981 \in \mathcal{N}_{-2}$	$1983 \in \mathcal{N}_{-4}$
$1985 \in \mathcal{N}_2$	$1987 \in \mathcal{N}_0$	$1989 \in \mathcal{N}_{-2}$	$1991 \in \mathcal{N}_2$	$1993 \in \mathcal{N}_0$	$1995 \in \mathcal{N}_{-2}$	$1997 \in \mathcal{N}_0$	$1999 \in \mathcal{N}_0$	$2001 \in \mathcal{N}_{-2}$

Author Contributions

Khandoker Mohammed Mominul Haque: Conceptualization, Formal Analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft

Umme Nasreen Khanam: Validation, Writing – review & editing

Khandoker Mohammed Faiyaz Shahriar: Validation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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